Assessment of Heavy Metal Contamination in Groundwater of Mapusa City

A Dissertation for

GEO-651 Dissertation

Credits: 16

Submitted in partial fulfillment of Master's Degree

MSc in Applied Geology

by

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Date: May 2024

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DECLARATION BY STUDENT

I hereby declare that the data presented in this Dissertation Report entitled, **"Assessment of Heavy Metal Contamination in Groundwater of Mapusa City"** is based on the results of investigations carried out by me in the Master of Applied Geology at the School of Earth Ocean and Atmospheric Sciences, Goa University under the Supervision of Mr. Mahesh Mayekar and the same has not been submitted elsewhere for the award of a degree or diploma by me. Further, I understand that Goa University or its authorities will not be responsible for the correctness of observations / experimental or other findings given the dissertation.

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This is to certify that the dissertation report **"Assessment of Heavy Metal Contamination in Groundwater of Mapusa City"** is a bonafide work carried out by Ms. Tejashree Alias Sonal Dnyaneshwar under my supervision in partial fulfillment of the requirements for the award of the degree of Master in Science in the Discipline Applied Geology at the School of Earth Ocean and Atmospheric Sciences, Goa University.

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PREFACE

Groundwater, the invisible and vital component of our planet's hydrologic cycle, is facing an insidious threat from heavy metal contamination. The slow and silent creep of heavy metals into our groundwater resources poses a significant risk to human health, the environment, and the economy. This dissertation delves into the complex relationships between groundwater, heavy metals, and human activities and sources, fate, and transport of heavy metal in the aquifer, with a focus on the groundwater of Mapusa City. The presence of heavy metals in groundwater is a pressing concern, as they can have devastating effects on human health, including cancer, organ damage, and neurological disorders. The environmental impacts are equally alarming, with heavy metals contaminating soil, water, and air, and disrupting the delicate balance of ecosystems.

Through meticulous sampling and rigorous analysis, this study aims to provide insights into the current state of groundwater in the area, particularly focusing on post-monsoon conditions. The comprehensive analysis of groundwater was done through the usage of various indices such as the Heavy Metal Pollution Index (HPI), Metal Index (MI), and Water Quality Index- Weighted Arithmetic Method (WQI).

Further, to get the overall groundwater quality different parameters were analyzed such as pH, Electrical Conductivity (BC), Total Dissolved Solids (TDS), and the determination of major cations like Calcium, Magnesium, Sodium, and

Potassium. Furthermore, heavy metal concentrations, including Iron (Fe), Manganese (Mn), Copper (Cu), and Zinc (Zn), were evaluated using advanced analytical techniques, with comparisons made against established standards for drinking water quality. Moreover, the determination of Total Hardness through the EDTA titrimetric method offers valuable insights into the overall water quality and its suitability for drinking purposes. In addition, a groundwater flow net is prepared to get an idea of the groundwater flow and the pollutant's pathway.

By synthesizing these findings, this research contributes to the broader understanding of groundwater quality dynamics and aids in informed decision-making for sustainable water resource management and public health protection. It is hoped that the outcomes of this study will serve as a foundation for future research endeavors and policy interventions aimed at safeguarding the precious resource of groundwater for generations to come.

Sincerely,

Tejashree Alias Sonal Dnyaneshwar Chari

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I want to offer my heartfelt appreciation to everyone who helped me with my MSc Dissertation. First and foremost, I want to express my gratitude to my supervisor Mr. Mahesh Mayekar, Assistant Professor, Applied Geology, SEOAS, Goa University who has been an important source of support and direction throughout my research journey. His extensive knowledge, skills, and views were invaluable in influencing my Dissertation and assisting me in gaining a better understanding of the subject area. I am appreciative of his patience, politeness, and continuous support in assisting me in meeting my academic objectives.

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ABBREVIATIONS USED

ENTITY	ABBREVIATION
Bureau of Indian Standards	BIS
Electrical Conductivity	EC
Heavy Metal Pollution Index	HPI
Metal Index	MI
Total Dissolved Solids	TDS
Water Quality Index	WQI
World Health Organisation	WHO

ABSTRACT

The study was conducted in Mapusa City, Goa, wherein heavy metals such as Fe, Zn, Cu, and Mn were analyzed in groundwater samples. The 15 groundwater samples were spaced in such a way that they covered the entire city. In addition, physiochemical parameters (pH, EC, TDS) and major cations (Ca, Mg, Na, K) were analyzed. The heavy metals were analyzed by ICAR, wherein 11 well water samples were chosen based on the anomalies found during the field tests.

The overall pH of groundwater samples was acidic due to rainfall, and one well had basic pH due to being the deepest well which had low Carbon Dioxide concentration. The EC and TDS were found to be higher in 9 water samples due to the presence of dissolved solids of minerals and salts. The Calcium, Sodium, and Potassium were within the permissible limits as per the various guidelines. However, Magnesium was found to be higher than the permissible limits in 7 wells due to weathering of Laterite.

According to the groundwater flow net, the groundwater was flowing towards the Moira River in the southern part of the map and to the Haran River in the northern portion. The overall hydraulic conductivity was gentle and steady as depicted by evenly spaced equipotential lines.

According to HPI and MI, all the well water samples were safe for drinking purposes except for the Well 10 which had the highest concentration of heavy metals, wherein Mn was the major contributor. As per WQI, only two well water

samples were found to be of good quality, and 5 wells were considered unfit for human consumption.

The Fe concentration was higher in 4 water samples due to weathering of Laterite. The Zn concentration was within the permissible limits. The Mn concentration was detected in only one water sample, wherein that sample had an Mn concentration higher than the permissible limit. The Cu concentration was in very minute quantities that it became undetectable in all water samples. The overall water quality was poor, however as far as heavy metals were concerned most of the water samples were safe for drinking purposes.

CHAPTER 01: INTRODUCTION

1.1 GENERAL INTRODUCTION

The groundwater is present in the form of wells and springs, which is considered one of the most filtered water present in nature compared to surface water due to soil cover which acts like a filtering media. In India groundwater is widely used as a potable source of water, it is also used for domestic, industrial, and irrigation purposes (Wagh et al. 2018). Due to urbanization, freshwater resources are getting depleted as a result of over-exploitation (Dheeraj et al. 2023). The groundwater is not directly exposed to the atmosphere, however, it is at risk of getting contaminated by heavy metals which are poisonous and hazardous to health because of its non-biodegradable and accumulation over time properties (Sobhanardakani et al. 2012).

Heavy metal is a pollutant that has an atomic density higher than 4000 kilograms per meter cube (Hashim et al. 2011). Selective heavy metals in very small quantities are required for the well-functioning of the human body and to increase metabolism, however, higher quantities have lethal effects on the human body, and some heavy metals even in minute quantities show adverse effects on the human body. As a consequence of this, it becomes our priority to monitor the heavy metals concentration regularly in certain intervals of time (Wagh et al. 2018).

There are various pathways through which a heavy metal can get into our food chain. Humans can get exposed to heavy metals which are a natural part of Earth's crust through inhalation of heavy metal dust, intake of heavy metal in the form of potable water, or through direct contact with skin as dust particles (Wagh et al. 2018).

Moreover, the sources through which heavy metal can be released in groundwater are of two types, natural and anthropogenic. The natural sources include the decomposition of living matter and weathering of rocks and soils that contain heavy metal within them. The anthropogenic sources include mineral and mining processing, agricultural such as fertilizers and pesticides, industrial waste dumping in water or on barren land, medicinal waste, and municipal waste like body care, paints, plastic, and inks (Wagh et al. 2018).

Various heavy metal pollution indices can be used to detect the overall quality of the groundwater. In this study, we use HPI (Heavy Metal Pollution Index) and MI (Metal Index) to deduce the groundwater quality in Mapusa City using groundwater samples. The 15 groundwater samples are spaced in such a way that they cover up the entire Mapusa City.

1.2 PHYSIOGRAPHY OF GOA

Goa lies on the west coast of India between N 14°53’ and N 15°48’, the western and eastern extents are approximately E 73°39’ and E74°29’. The total area of the state is 3702 sq. km with coastline stretching to a length of 105 sq. km. The state is broader in the north and narrower in the south. The state is bordered in the north by Maharashtra, the east and south by Karnataka, and to the west by the Arabian Sea. Physiographically, the state of Goa is divided into three terrains. At the west, east, and central there are low-lying coastal-estuarine plains, steep slopes of the Western Ghats, and an undulating region respectively.

1) The western coastal-estuarine plains with tablelands: The estuarine plains extend up to 10 to 12km inland. This terrain consists of saltpans, khazan lands, estuarine mudflats, sandy beaches, mangroves, fields, and settlement areas. The plains are found to be prominent in North Goa, however, these are not uniform all over the area because of the interruption of rocky tablelands that abut the seafront.

2) The Central undulating region: This region is also known as the midlands which contain relict hills ranging from 100 to 600m. This region is the transition between western ghats and coastal plains. All the valleys and the hills present in this region are aligned in the NW-SE direction which is exactly parallel to the coastline of the Goa, wherein, the trend is controlled

by folding and schistosity of the rocks in the hills. However, it is difficult to differentiate midlands from western ghats with precision in the South of Goa because of rugged mountain ranges.

3) The Western Ghats: This region is also known as Sahyadris which has a trend of NW-SE, except in South Goa the trend is WNW-ESE. The hill ranges in this region are 600 to 1000 m high and they cover up the eastern and southern areas of the state. The western part of the ghats meets the sea, as a result, Quepem and Canacona taluka have limited exposure to coastal estuarine plain and midlands region (Fernandes, 2009).

1.3 GEOLOGY OF GOA

As per Gokul et al. (1985), the Goa Group of rocks is broadly divided into the Barcem Group and the Ponda Group. The Barcem group contains mainly Greenstones known as metabasalts with a basement of 3300Ma to 3400Ma old Anmode Ghat Trodhjemite Gniess which shows similarity with the Babubudan Group of Dharwar. The unconformity is marked by Quartz pebble conglomerate.

The Ponda group is predominately made up of clastics which shows similarity with the Chitradurga Group of Dharwar with the basement of 2700-2900 Ma Chadranath Granite Gneiss wherein the unconformity is marked by polymict, granite-clast meta conglomerate. This conglomerate shows similarity with the Talya Conglomerate which lies as an unconformity for the Chitradurga group. The Ponda Group is further divided into formations such as the Sanvordem Formation, Bicholim Formation, and Vageri Formation.

The Sanvordem formation contains mainly metagraywackes, quartzites, tilliods, and Argillites. The Bicholim formation is made up of BIF, phyllites, limestones, metagreywacke, schists, chert, breccia, and argillites. The Vageri formation contains meta basalts, argillites, and metagraywackes. The Ponda Group contains turbite sequence with intercalations of mafic volcanic. The Bondla layered mafic-ultramafic complex is intruded along a shear zone on the top of the Ponda Group. At last, it is overlain by Canacona potassic granite intrusives. Deccan traps are the last intrusives in some parts of Goa. The most recent strata is a residual product also known as Laterite in Goa which covers almost the entire surface of Goa. Table 1.1 illustrates the lithostratigraphic classification of Supracrustal rocks from Goa.

Table 1.1: Lithostratigraphic classification of Supracrustal rocks from Goa (Dessai, 2011)

Residual rocks		Laterites
Basic Intrusives (Late)	65-66 Ma	Dolerites
Deccan Traps	64-67 Ma	Basalts
Basic Intrusives		Meta dolerite
Bondla Mafic Ultramafic Complex		Dunite-Peridotite-Gabbro and equivalents
Ponda Group (Chitra Durga Group)	Vageri Formation	Meta basalts, Argillites and Metagraywackes
	Bicholim Formation	Banded Ferruginous quartzites, Manganiferous Chert Breccia with pink ferruginous phyllites, Limestones, Pink ferruginous phyllites, quartz-Chlorite-Amphibole Schist, Metagreywacke, Argillite
	Sanvordem Formation	Metagraywackes, Argillites, Quartzite, Tilloid
-----------------------------------Unconformity-----------------------------------		
Barcem Group (Bababudan Group) Barcem Formation	Barcem Formation	Metagabbro, Peridotite, Talc Chlorite Schist Quartzite, Quartz-Sericite Schist Red Phyllite Quartz Porphyry Massive, Schistose and Vesicular Metabasalt
-----------------------------------Unconformity-----------------------------------		
Canacona Granite	2979+4 Ma	Potassic Porphyritic Granite
Chandranath Granite Gneiss	2900-2700 Ma	Granodiorite Gneisses
Basement: Anmode Ghat Trondjemite Gneiss	3400-3300 Ma	Tonalite-Trondjemite-Granodiorite (TTG) Gneiss

1.4 DETAILS OF STUDY AREA

Mapusa City is located at 15.60°N, 73.82°E and lies on the banks of Mapusa River which is one of the main tributaries of Mandovi River. The Mapusa River originates from the jungles of Amthane and Dumacem and meanders eastward and then southward before it joins the Mandovi River. The Haran River flows in the northern part of the city. It has an average elevation of 15m from mean sea level. Mapusa City has a tropical climate with average temperatures ranging from 28°C to 32°C. The average humidity is 21°C in winter. The average, minimum, and maximum elevation is 26m, -3m, and 110m respectively. The Ghateshwar Nagar region boasts the highest elevation in that area. The city has laterite tablelands wherein laterite is the duricrust. The city is entirely comprised of a sedimentary rock known as Argillite, which is characterized by its composition of Quartz, Feldspars, and Illite. The Argillite contains high amounts of Silica and Aluminum. The soil found in this region is mainly lateritic. The average rainfall in an annum is 2700mm, however, there are brief periods of aridity. The aquifer in this region is made up of Laterites. There is an industrial estate in Thivim and agricultural lands in the central portion of the study area. In the north, northeast, and south, there are low-lying areas rich with trees and crops. Figures 1.2, Figure 1.3, Figure 1.4., Figure 1.5, and Figure 1.6 display the topography, drainage, geology, and land cover of the region.

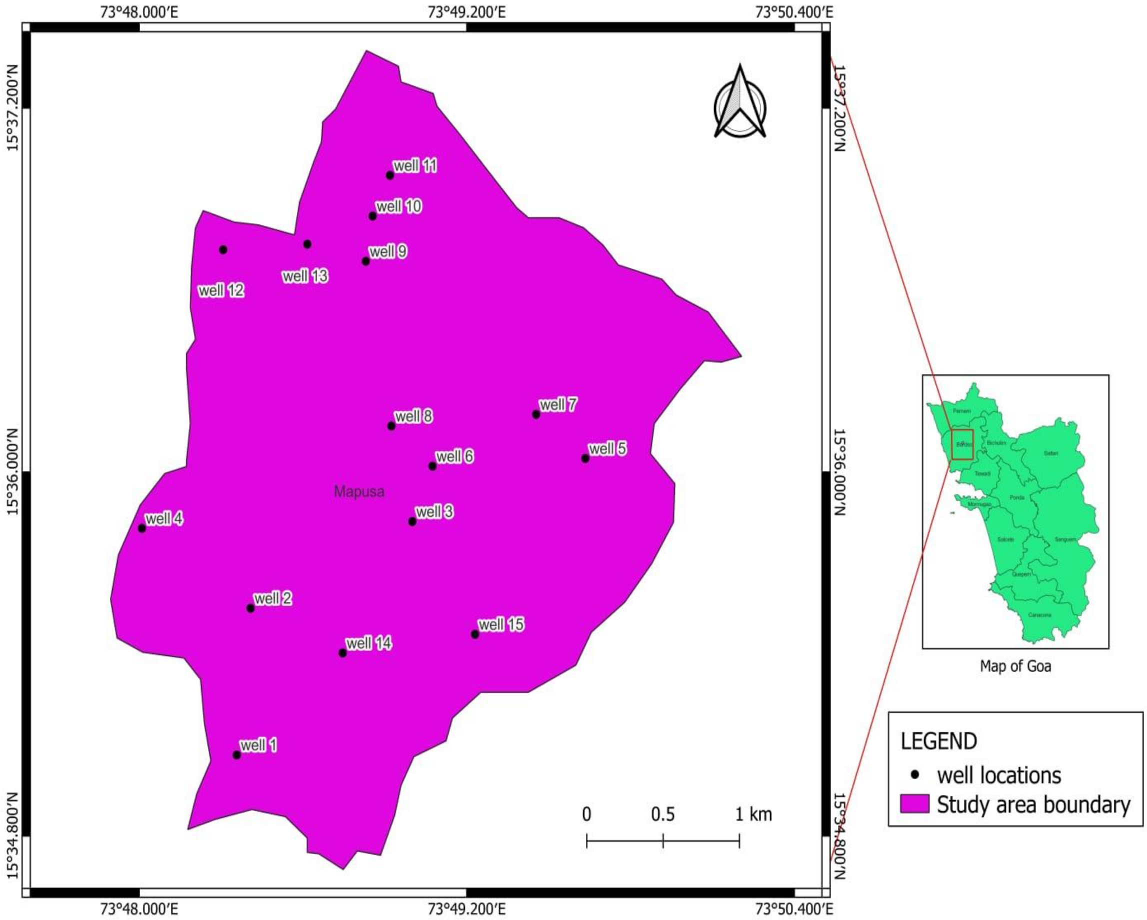

Figure 1.2: Study Area Map - Mapusa City

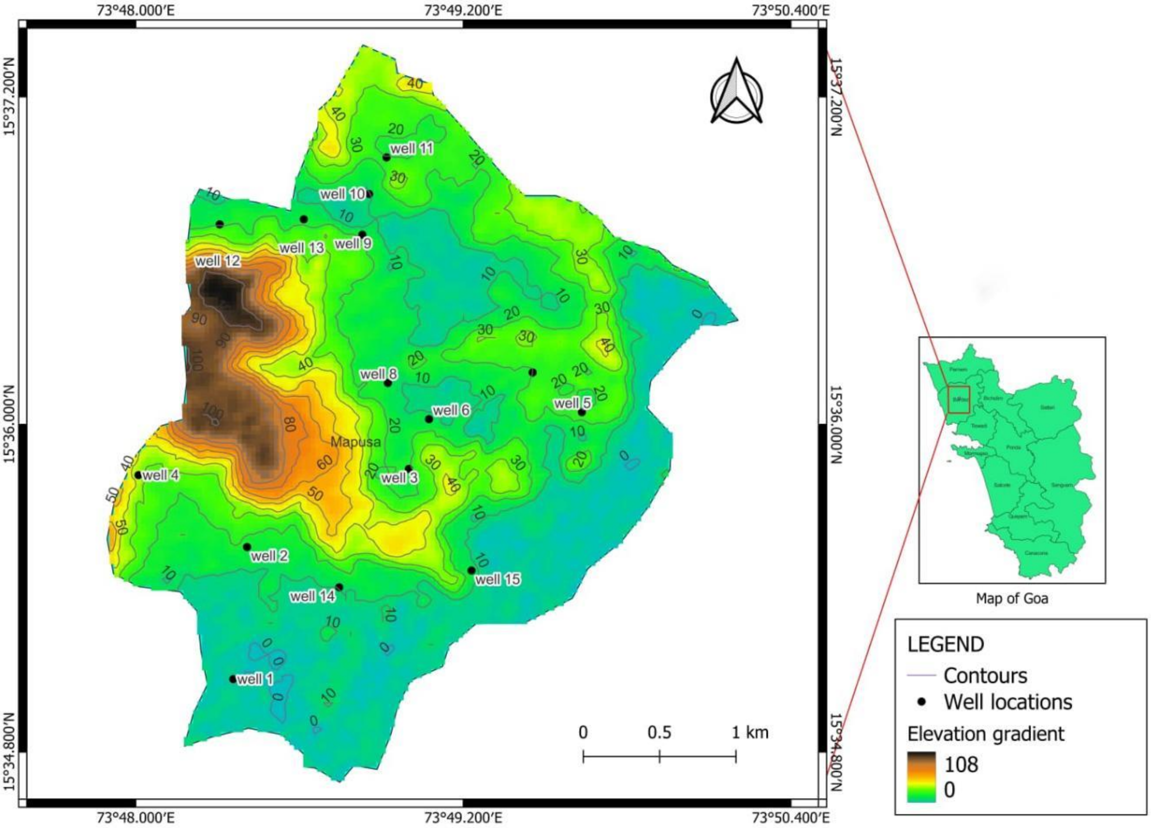

Figure 1.3: Topography Map of Mapusa City

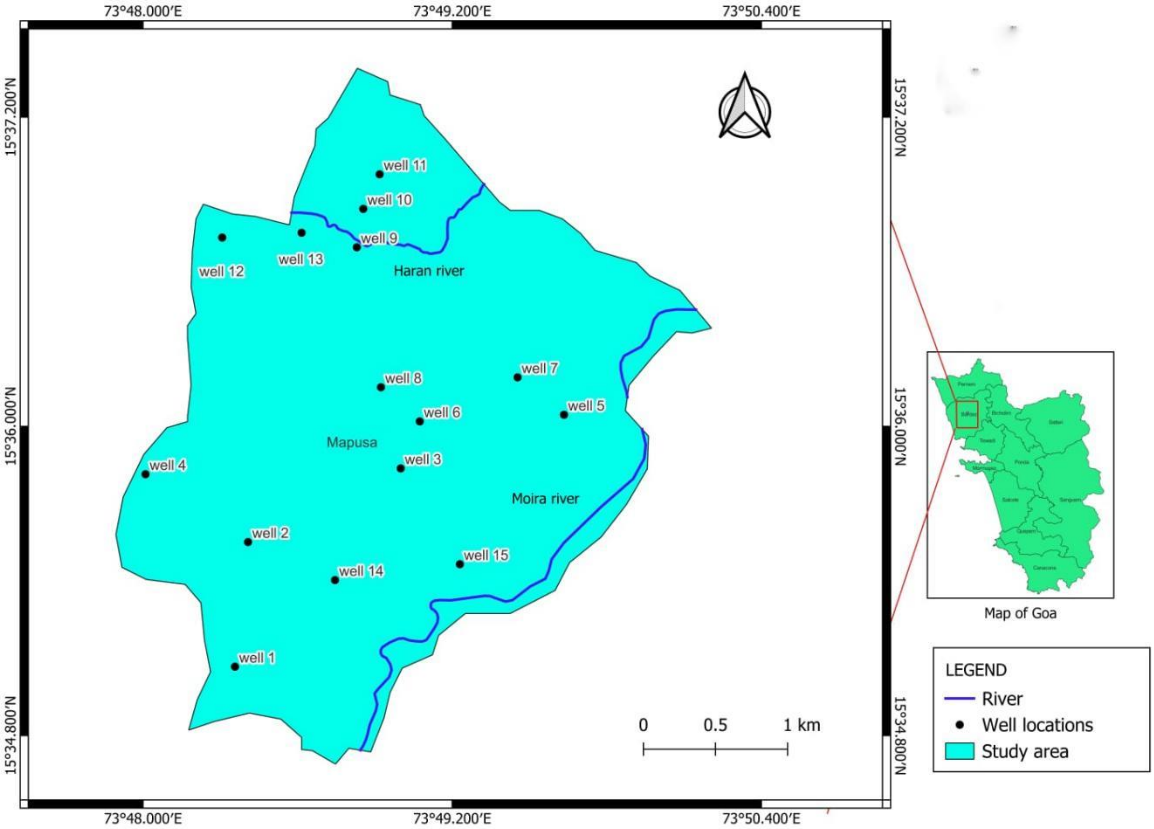

Figure 1.4: Drainage Map of Mapusa City

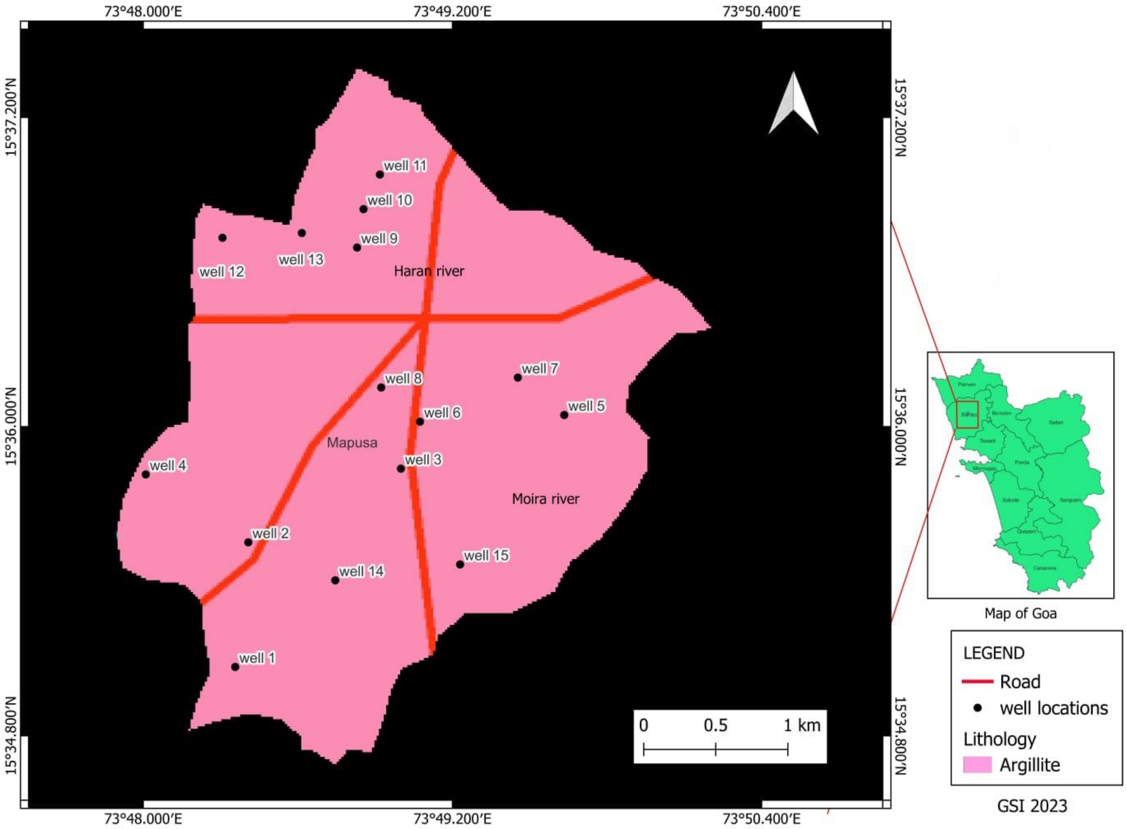

Figure 1.5: Geology Map of Mapusa City

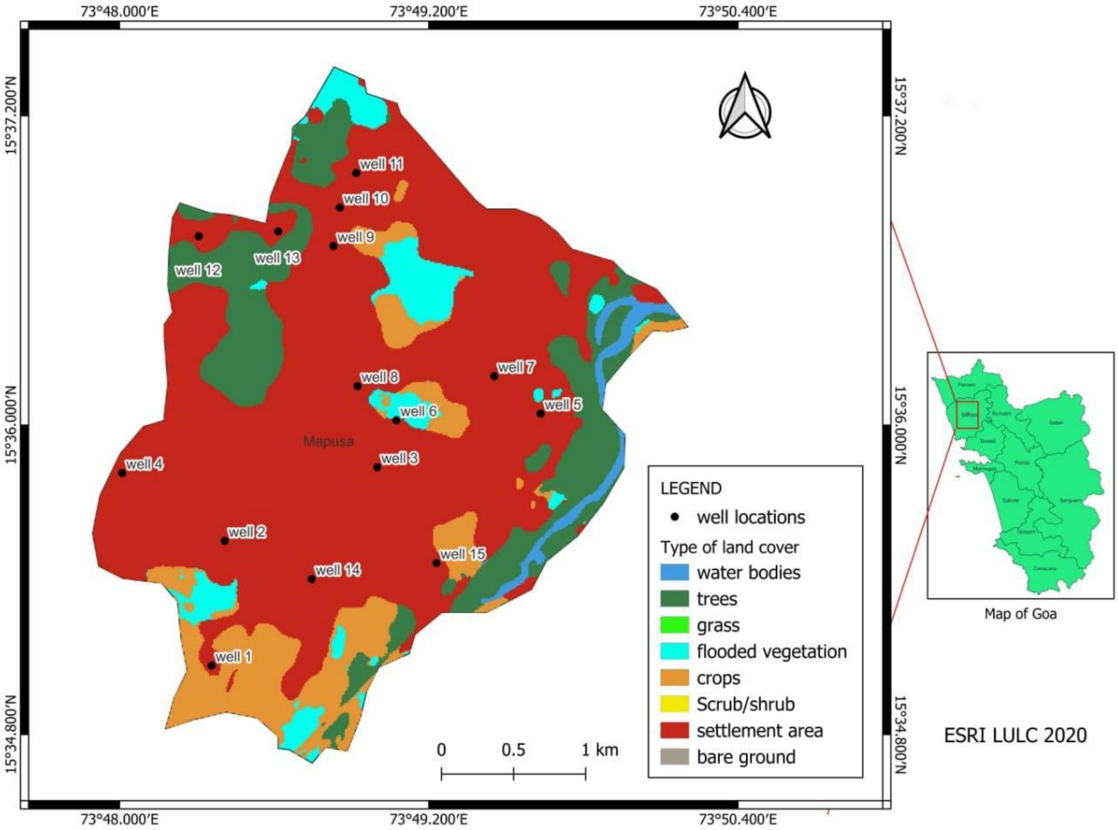

Figure 1.6: Land Cover and Land Use Map of Mapusa City

1.5 OBJECTIVES

The objectives of our study are:

1. To prepare a groundwater flow net
2. To study carcinogenic risk using HPI (Heavy Metal Pollution Index) and MI (Metal Index)
3. To check the water quality using a Water Quality Index
4. To check the suitability of groundwater for drinking purposes concerning heavy metals

CHAPTER 02: LITERATURE REVIEW

The literature review on groundwater analyses of Mapusa city revealed that the study area is not analyzed using indices such as HPI (Heavy Metal Pollution Index) and MI (Metal Index). Different research papers have been studied from different areas and environments to get a better idea about the indices.

The health risk assessment of heavy metal contamination in groundwater of the Kadava river basin in Nashik was done using ICP-AES, wherein different heavy metals were analyzed. The study done by Wagh et al. (2018), concluded that the groundwater quality was poor based on the HPI, HEI, Cd, And HI that Pb, Ni, Cr, and Fe were above the permissible limit in all samples, which attributed the contamination to intense agriculture, land use patterns, leaching of fertilizer, pesticides, and domestic waste in the aquifer system. A study in the coal mine of the Korba Coalfield conducted by Singh et al. (2017) using ICP-OES concluded that there was a high concentration of heavy metals such as Mn, As, and Fe in the groundwater samples of post-monsoon and pre-monsoon based on heavy metal indices. The study discovered that the groundwater contamination in this region was due to geogenic and anthropogenic activities combined.

The study conducted by Kumar et al. (2020) using ICP-MS for heavy metal contamination in an industrial area of Ramgarh in Jharkhand revealed that there was a high concentration of Fe based on heavy metal indices which attributed its sources to, non-ferrous alloys, sponge iron, foundry, Ferro alloys, instrument manufacturing, and welding industries present around the study area. A study conducted in Chandigarh by Ravindra et al. (2019), suggested that the groundwater quality was poor using heavy metal indices and geospatial interpolation of contaminants identified agrarian activities, poor sanitary practices of waste management, and industrial pollution as the prominent sources of groundwater contamination. Furthermore, municipal solid waste dumping and industrial areas around the region showed high concentrations of heavy metals such as Pb, Ni, Cd, and Zn.

Assessment of groundwater quality in the Peenya Industrial area was done by using the Heavy Metal Pollution Index (HPI) and Metal Index (MI) by Anitha et al. (2021). The heavy metals found in the order Cr>Pb>Ni>Fe>Cd. The study revealed that 83.33% of groundwater samples were unsuitable for drinking purposes as they had high HPI values. With regards to MI, 73% of groundwater samples were seriously affected by heavy metal contamination due to the effect of urbanization and industrialization in the study area.

A study was conducted near the Karsara Municipal landfill site, in Varanasi, India by Mishra et al. (2018), wherein the Water Quality Index (WQI) was determined by using the weight arithmetic method. The study revealed that the study area near the landfill site is in the fair category during pre-monsoon seasons but in the threatened category during post-monsoon season. The results of the physiochemical analysis of groundwater have shown that the water was not safe for drinking purposes as parameters like TDS, Hardness, Total Alkalinity, and Nitrate and Iron content were above acceptable limits as per WHO and BIS guidelines. It was concluded that the groundwater quality deteriorated around landfill sites in Varanasi City.

Since the study area is a city, wherein proper dumping of Municipal waste is an issue to tackle, the heavy metals in the groundwater regime are usually leached out due to Municipal waste. Including this lateritic terrain can play a role in the heavy metal contamination to an extent because Laterite is a residual product that can contain heavy metals in its structure and due to being in continuous contact with groundwater, the heavy metals can leach out into the groundwater regime as a consequence of weathering.

CHAPTER 03: METHODOLOGY

3.1 PRE-FIELD PREPARATION

As a pre-field preparation, a base map was created using QGIS, wherein the study area boundary was defined using a regional development plan of 2016 at a scale of 1:5000. Utilizing the Survey of India toposheet 48E14-SW-A2, approximate well locations were deduced by overlapping the toposheet on Google Earth Map. After getting the approximate well locations, these were pinned up on Google Maps, and a reconnaissance survey in the field was conducted to get the exact locations which were then plotted on a base map using QGIS, as depicted in Figure 3.1.

3.2 FIELD DATA COLLECTION

The field data and the groundwater samples were collected in a three-day field trip in December 2023. The concerned 15 well locations were spaced all around Mapusa City to get wide and accurate data. The latitude and longitude of all 15 well water samples are given in Table 3.2. The field data was collected and documented systematically as shown in Table 3.3. Along with this, the overall depth of the well and groundwater water level, and the thickness of the water column were deduced using a depth measuring tape. For laboratory analyses for heavy metals in ICAR, 11 well water samples were taken based on anomalies found during field tests.

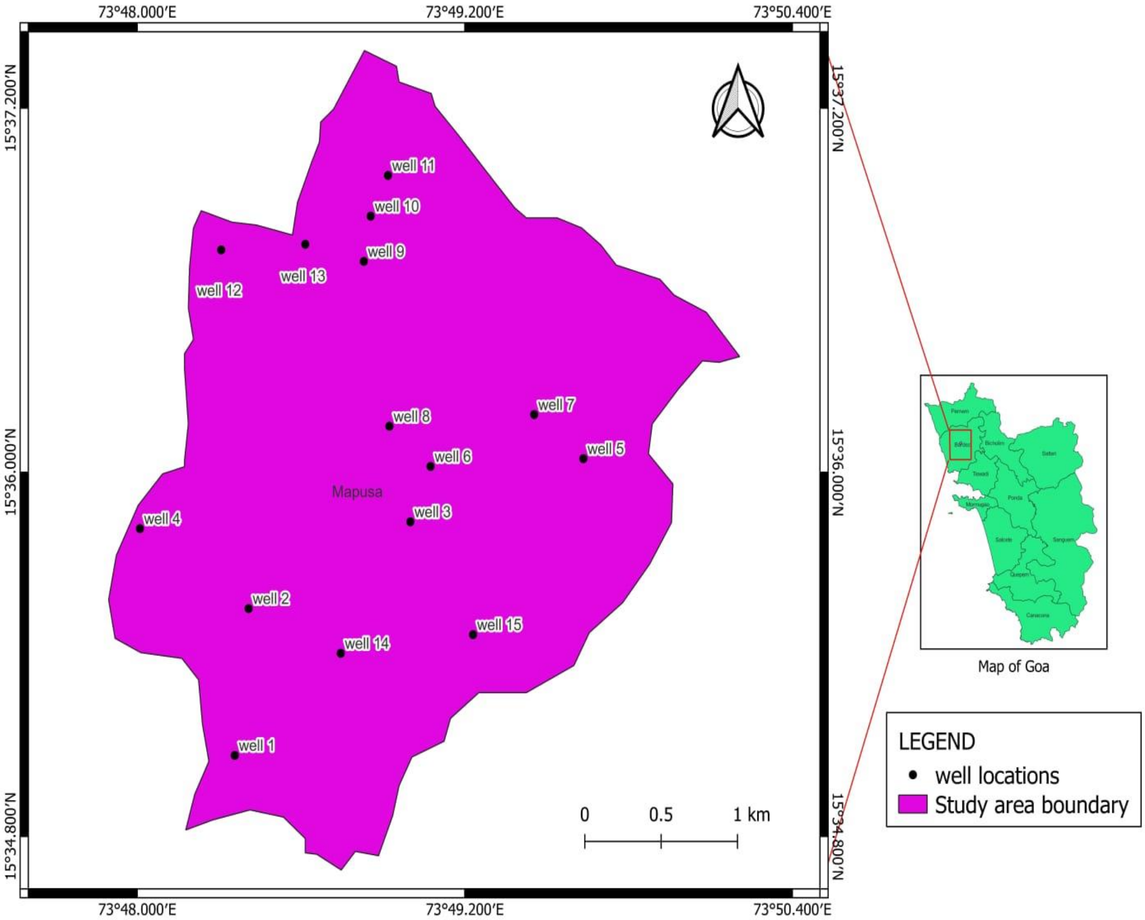

Figure 3.1: Study Area Map with well locations

Table 3.2: Latitude and Longitude of the study area

WELL ID	LATITUDE (DECIMAL)	LONGITUDE (DECIMAL)
1	15.5844540	73.8059550
2	15.5925160	73.8068000
3	15.5972810	73.8166730
4	15.5969050	73.8001690
5	15.6007500	73.8272370
6	15.6003200	73.8179070
7	15.6031700	73.8242330
8	15.6025290	73.8153970
9	15.6115820	73.8138350
10	15.6140660	73.8142520
11	15.6163030	73.8153120
12	15.6118000	73.8051200
13	15.6122000	73.8102300
14	15.5900570	73.8124250
15	15.5910833	73.8205000

Table 3.3: Data recording format

SERIAL NO.	
WELL ID	
LATITUDE	
LONGITUDE	
DEPTH OF GROUNDWATER LEVEL (METERS)	
TOTAL WELL DEPTH (METERS)	
THICKNESS OF WATER COLUMN (METERS)	
pH	
ELECTRICAL CONDUCTIVITY (µS/cm)	

3.2.1 FIELD TESTS

A. pH

The pH of all 15 well water samples was determined in situ using a pH probe known as the FiveGo-Mettler Toledo portable pH meter. The pH was prior calibrated using standard pH solutions. The pH readings of all samples were obtained and documented by following the procedure given below.

Procedure:

1. The pH meter probe was rinsed with the immediately drawn water sample.
2. The probe was turned on by pressing the switch button given.
3. Immediately after pressing number 7.00 should flash on the screen of the probe.
4. Insert the probe vertically into the water sample and make sure that the tip of the probe is at least half an inch immersed in the sample.
5. Wait for a few seconds to hear the beep sound from the probe.
6. Take note of the number flashing on the screen, since it is the pH value of that sample.
7. After getting the reading, make sure to again keep the probe back at a vertical angle inside the box provided.

B. ELECTRICAL CONDUCTIVITY (EC)

The EC of all 15 well water samples was determined in situ using a probe called Solinst TLC EC Meter. The readings were obtained and recorded in the microSeimens per cm (µS/cm) unit. The following procedure was followed to obtain the EC of every sample.

Procedure:

1. The EC meter probe was rinsed with the immediately drawn water sample.
2. The probe was turned on by pressing the switch button given.
3. Immediately after pressing the number 0.00, it should flash on the screen of the probe.
4. Insert the probe vertically into the water sample and make sure that the tip of the probe is at least half an inch immersed in the sample.
5. Wait for a few seconds to hear the beep sound from the probe.
6. Take note of the number flashing on the screen, since it is the EC value of that sample.
7. After getting the reading, make sure to again keep the probe back at a vertical angle inside the box provided.

C. TOTAL DISSOLVED SOLIDS (TDS)

The TDS of all 15 samples was obtained by calculating the below formula. The unit of TDS is milligrams per Liter (mg/L).

TDS = Electrical conductivity of the sample × 0.64 (CGWB, 2021).

3.3 FIELD DATA COLLECTION

After the completion of field tests, the well water samples were acidified with 68% conc. Nitric acid to prevent any precipitation of heavy metals inside the sample bottles (500 mL). The sample bottles were air-tight and transferred to the refrigerator at 3°C to restrict any activity of microorganisms.

3.3.1 LABORATORY TESTS

A. ESTIMATION OF SODIUM AND POTASSIUM

The Sodium and Potassium presence in each of the well water samples was determined using an instrument known as a Microcontroller Flame Photometer (Labtronics model LT- 6710). The readings were noted down in parts per million (PPM). The following approach to find the readings is given below.

Procedure:

1. The main switch was turned on and the compressor back button was pressed.
2. To turn on the Gas cylinder, turn the knob on.
3. The back button of the instrument was long pressed till we didn't see the flame ignition.
4. Then press on analysis, G- on the flame photometer screen.
5. After this, click on the Batch name and g-na-k.
6. The option for distilled water run will flash on the screen, choose the yes option on the screen before proceeding with the analysis make sure the flame is blue
7. If there are bubbles in the small tube attached to the instrument, the flame will appear red, to remove the bubbles tap on the small tube till most of the bubbles are removed through suction.
8. Once the distilled water sample is run, there will be an option flashing on the screen to run the sample. Transfer the well water sample of around 30mL to a small beaker, insert the small tube in the sample, wait till the flame is red, and then click on the Yes option on the screen.
9. The exact amount of Sodium and Potassium will flash on the screen, note it down for further reference.

B. TOTAL HARDNESS

Total Hardness was estimated by titration method [EDTA Titrimetric; ID:1.12 (S.A.P., May 1999)]

Requirements: Beaker, Conical flask – 250mL, Eriochrome black- T indicator, 0.02NEDTA solution, Ammonium chloride buffer solution, Distilled water, pipette, Burette, etc.

Preparation of Reagents:

1. Preparation of 0.02N EDTA titrant- take 3.273g of EDTA powder and dissolve it in 1000mL of distilled water.

2. Preparation of Ammonium Buffer- To prepare the Ammonia buffer solution. Dissolve 16.9g ammonium chloride in 143 ml concentrated ammonium hydroxide (NH_4OH). Add 1.25g magnesium salt of EDTA and dilute to 250 ml with distilled water. If magnesium salt of EDTA is not available, dissolve 1.179g disodium salt of EDTA (AR) grade and 780 mg $MgSO_4.7H_2O$ or 644 mg $MgCl_2.6h_2O$ in 50 ml distilled water. Add this to the above solution of NH_4Cl in NH_4OH and dilute to 250ml.

3. Preparation of Eriochrome Black T indicator- Dissolve 0.5g of Eriochrome black T indicator in 80mL of 90% ethanol and makeup to 100mL with 95% ethanol.

Procedure:

1. Rinse and fill the burette with 0.02N EDTA solution.

2. Rinse and pipette out 25mL of water sample in a clean 250mL conical flask and add 1mL Ammonium buffer.

3. Now add a few drops of Eriochrome black T indicator into the flask and titrate it against 0.02N EDTA solution.

4. The endpoint is determined by a color change from wine red to blue.

Calculation:

Hardness = mL of the EDTA titrant *1*1000/ mL of a sample taken for titration

C. ESTIMATION OF CALCIUM HARDNESS

Estimation of Calcium Hardness was done using the titration method [EDTA Titrimetric 1.29 (S.A.P.)]

Following Titrimetric analysis was used to determine calcium hardness.

Requirements: Beaker, Conical flask – 250mL, Murexide indicator powder, 1N Sodium hydroxide solution, 0.02N EDTA sol., Distilled water, pipette, dropper, Burette, etc.

Preparation of Reagents:

1. Preparation of 0.02N EDTA titrant- take 3.273g of EDTA powder and dissolve it in 1000mL of distilled water.

2. Preparation of 1N Sodium Hydroxide Solution: Weigh 4.5g of sodium hydroxide in 100 mL distilled water and allow it to cool.

Procedure:

1. Rinse and fill the burette with 0.02N EDTA solution.

2. Rinse and pipette out 25mL of water sample in a clean 250mL conical flask and add 2mL NaOH solution.

3. Now add a pinch of Murexide indicator powder to the sample solution and titrate it against 0.02N EDTA solution.

4. The endpoint is determined by the change in color from pink to purple.

Calculation:

Calcium = mL of EDTA titrant*0.01*40.008/ mL of the sample taken for titration*1000

D. ESTIMATION MAGNESIUM HARDNESS

Estimation of Magnesium Hardness was done through calculations [Calculation from Total Hardness and Calcium; ID: 1.36 (S.A.P., May 1999)]

Magnesium = (Total Hardness – Calcium Hardness) * 0.243

3.3.1 HPI, MI and WQI CALCULATIONS

A. HEAVY METAL POLLUTION INDEX (HPI)

HPI is one of the indices that give the overall quality concerning heavy metal concentration in water samples.

Wi = Unit weightage of the i^{th} heavy metal

n = Number of heavy metal

Qi = Subindex of the i^{th} heavy metal

K = Proportionality constant (K = 1)

Si = Standard permissible limit for i^{th} heavy metal (max. permissible limit value)

Mi = Monitored value of heavy metal of the i^{th} heavy metal

Ii = Ideal value of the i^{th} heavy metal (Acceptable limit value)

HPI is classified as low (0-15), Medium (15-30), and High (>30). If the value is <100 then water is safe to consume and if the value is >100 then water is critical or unfit to consume (Wagh et al. 2018).

For calculating HPI through MS-Excel, the following constants were used Si: Fe (1000 ppb), Zn (300 pbb), and Mn (15000 pbb). Ii: Fe (300 ppb), Zn (100 pbb), and Mn (5000 pbb). The monitored values should be converted to ppb by multiplying the value in ppm by 1000.

STEP 01: Calculate the Unit Weightage of the heavy metal

$$Wi = \frac{K}{Si}$$

STEP 02:Calculate the Proportionality Constant

$$K = 1/\sum_{i=1}^{n} 1/Si$$

STEP 03:Calculate the Subindex of the heavy metal

$$Qi = \sum_{i=1}^{n} \left(\frac{|Mi - Ii|}{Si - Ii} \right) * 100$$

STEP 04:Calculate the overall HPI value

$$HPI = \sum\nolimits_{i=1}^{n} WiQi/\sum\nolimits_{i=1}^{n} Wi$$

B. METAL INDEX (MI)

MI is one of the indices that gives the overall quality of heavy metal concentration in water samples. When the calculated MI value is >1, it signifies that the water samples are polluted with heavy metals and the degree of pollution worsens with increasing MI values. However, when the calculated MI value is <, it signifies that the water samples are safe or free from heavy metal contamination (Bakan et al., 2010).

Ci = Monitored value

MAC = Maximum admissible concentration of the ith parameter

MI is classified as illustrated in Table 3.4

(Ci and MAC values should be converted to ppb)

Class	Property/Characteristics	MI Values	
I	Very Pure	<0.3	MI <1
II	Pure	0.3 -1	
III	Slightly Affected	1-2	MI >1
IV	Moderately Affected	2-4	
V	Strongly affected	4-6	
VI	Seriously affected	>6	

Table 3.4: MI classification table

$$MI = \sum_{i=1}^{n} Ci/MACi$$

C. WATER QUALITY INDEX (WQI)

The Water Quality Index is calculated using the Weighted Arithmetic Index Method. The main objective of WQI is to turn complex water quality data into an understandable to the general public. The Water Quality Index calculations involve 3 steps (Brown et. al., 1972).

Step 1: Calculate the Unit Weight (Wn) factors for each parameter by using the formula:

$$Wn = K/Sn$$

$$K = 1/\sum 1/\Sigma Si$$

Wn = Unit Weight

K= Constant (1)

Sn = Standard desirable value of the nth parameters

On summation of all selected parameters unit weight factors, Wn=1.

Step 2: Calculate the Sub-Index (Qn) value using the formula:

$$Qn = \frac{Vn - Vo}{Sn - Vo} * 100$$

$$QpH = \frac{VpH - 7}{8.5 - 7} * 100$$

Vn = Mean concentration of the nth parameters

Sn = Standard desirable value of the nth parameter

Vo = Actual values of the parameters in pure water (generally Vo = 0, for most parameters except for pH

Step 3: Calculate Step 1 & Step 2, WQI is calculated as follows:

$$OVERALL\ WQI = \sum WnQn / \sum Wn$$

CHAPTER 04: HYDROGEOLOGICAL STUDIES

4.1 INTRODUCTION

The aquifers in the present study area are made up of Lateritic and alluvial soils which are known for their good porosity and permeability. Due to high levels of weathering, these soils help in quick recharge in monsoon seasons. The study area receives an annual rainfall of 2700mm.

The groundwater flow nets are made to get a better understanding of distribution, flow, and contamination in the water of that area. To prepare a groundwater flow net, we need to keep in mind that the angle of intersection of the flow line and equipotential line should be 90 degrees. Two flow lines and equipotential lines should not cross each other. Seepage occurring in each flow channel should be constant. The equipotential line is the line of constant hydraulic head and it is in the form curvilinear shape. The flow line tells us about the flow path in the concerned aquifer, wherein water flows from a higher elevation to a lower elevation.

To study groundwater regime it becomes important to be aware of the groundwater level, the total depth of the well, and the thickness of the water column. After studying groundwater flow, one can know where to dump municipal waste.

4.2 GROUNDWATER LEVEL

The groundwater level was deduced using a depth-measuring tape. To obtain the exact groundwater level of the well, we have to lower the tape into the well until the attached weight touches the topmost surface of the water level. In the present study area, it was found that 5 wells had deeper groundwater levels as shown in the table, and the rest were at shallower depths. The deeper groundwater level attributes its sources to higher elevation and the thickness of the water column in the region, wherein the deepest is 15.35 m in Well 5 and the shallowest is 0.35m in Well 10. The average groundwater level is 4m to 5m. The wells with their respective groundwater level are shown in Table 4.5.

Table 4.5: Groundwater level of the wells

WELL ID	LATITUDE (DECIMAL)	LONGITUDE (DECIMAL)	GROUNDWATER LEVEL (MTS)
1	15.5844540	73.8059550	2.10
2	15.5925160	73.8068000	7.10
3	15.5972810	73.8166730	4.60
4	15.5969050	73.8001690	9.15
5	15.6007500	73.8272370	15.35
6	15.6003200	73.8179070	2.05
7	15.6031700	73.8242330	12.20
8	15.6025290	73.8153970	3.70
9	15.6115820	73.8138350	2.05
10	15.6140660	73.8142520	0.35
11	15.6163030	73.8153120	2.45
12	15.6118000	73.8051200	5.45
13	15.6122000	73.8102300	2.75
14	15.5900570	73.8124250	2.40
15	15.5910833	73.8205000	1.50

4.3 TOTAL DEPTH OF WELL

The total depth of the well was deduced using a depth-measuring tape with a weight attached to it at the bottom. The procedure to obtain the total depth of the well is to lower the tape into the well till it touches the ground surface. To get accurate depth, the tape should be lowered until it bends. In the study area, there are 5 wells which are the deepest as shown in the table. The deepest depth is 17m in the Well 5 and the shallowest is 2.5m in the Well 10, which attributes its sources to the elevation and the topography of the region. Table 4.6 depicts the Total Depth of wells.

Table 4.6: Total Depth of the wells

WELL ID	LATITUDE (DECIMAL)	LONGITUDE (DECIMAL)	TOTAL DEPTH OF WELL (MTS)
1	15.5844540	73.8059550	7.10
2	15.5925160	73.8068000	8.40
3	15.5972810	73.8166730	7.65
4	15.5969050	73.8001690	9.90
5	15.6007500	73.8272370	17.00
6	15.6003200	73.8179070	5.00
7	15.6031700	73.8242330	14.80
8	15.6025290	73.8153970	8.20
9	15.6115820	73.8138350	3.50
10	15.6140660	73.8142520	2.50
11	15.6163030	73.8153120	4.60
12	15.6118000	73.8051200	9.90
13	15.6122000	73.8102300	4.40
14	15.5900570	73.8124250	6.55
15	15.5910833	73.8205000	4.25

4.4 THICKNESS OF WATER COLUMN

The thickness of the water column was deduced using depth-measuring tape with a weight attached to it at the bottom. To obtain the thickness of the water column, we have to subtract the groundwater level from the total depth of the well. It was found that Well 1, Well 8, Well 12, and Well 14 have the thickest water column with 4.55m, 4.05m, 3.6m, and 3.55m respectively. The variation in the thickness of the water column is mainly due to the elevation of the region, over-exploitation, and the groundwater recharge during the monsoon season. The wells with their respective water column are given in Table 4.7.

Table 4.7: Thickness of the water column in each well

WELL ID	LATITUDE (DECIMAL)	LONGITUDE (DECIMAL)	THICKNESS OF THE WATER COLUMN (MTS)
1	15.5844540	73.8059550	5.00
2	15.5925160	73.8068000	1.30
3	15.5972810	73.8166730	3.05
4	15.5969050	73.8001690	0.75
5	15.6007500	73.8272370	1.65
6	15.6003200	73.8179070	2.95
7	15.6031700	73.8242330	2.60
8	15.6025290	73.8153970	4.50
9	15.6115820	73.8138350	1.45
10	15.6140660	73.8142520	2.15
11	15.6163030	73.8153120	2.15
12	15.6118000	73.8051200	4.45
13	15.6122000	73.8102300	1.65
14	15.5900570	73.8124250	4.15
15	15.5910833	73.8205000	2.75

4.5 FLOW NET

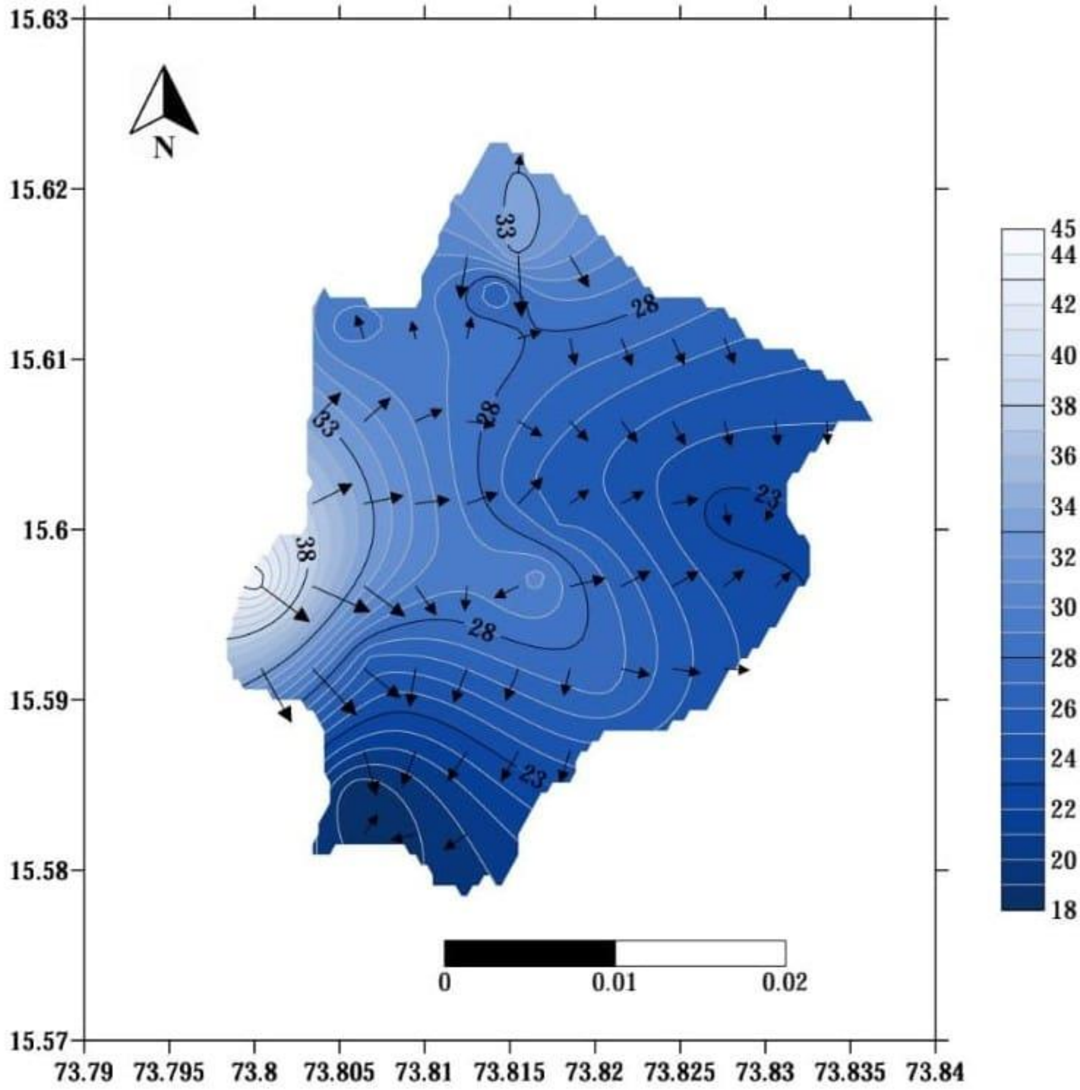

Figure 4.2: Groundwater Flow Net

(The values of groundwater level are in terms of Mean Sea Level)

(The Scale of the map is in Km)

4.6 INFERENCE

A flow net is a representation of the flow paths taken by water molecules through the sub-surface. The direction of groundwater flow in an unconfined aquifer is dependent on the hydraulic head, which is an indicator of the total energy available to move around through the aquifer, the hydraulic head at the water table is equal to the water table.

The groundwater in unconfined aquifers flows down a gradient from areas of the high hydraulic head to areas of low hydraulic head. Therefore, a map depicting the configuration of the water table elevation can be used to infer the direction of the groundwater flow. Groundwater flow nets of the study area have been prepared using water table elevation from means sea level and the elevations of that spot to understand the groundwater flow pattern. The equipotential lines are drawn for the study area marked with the flow directions with arrows as shown in the figure.

The groundwater flow net was prepared using the software Surfer 27, wherein, the ground elevation was deduced using Google Earth Pro, and the groundwater level was measured from the ground surface. For preparing the flow net groundwater water level was taken from Mean Sea Level. Figure 4.2 depicts the groundwater flow net.

Inference:

The general trend of groundwater is in the South and East directions. At the boundary of Mapusa City, towards the NE and SE directions, the Moira River is flowing. Most of the groundwater from the southern portion of the map joins to Moira River. Whereas, the groundwater from the northern portion of the map joins to Haran River which lies in the northern direction of the map as depicted by the flow direction arrows.

The northern and central portion of groundwater flows towards the East where there are low-lying areas such as Moira and the southern portion of groundwater flows towards the South where there are low-lying areas such as Bongini. The direction of groundwater flow suggests it was replenishing the rivers, indicating they had an effluent nature.

It was observed that in the extreme south and southeast wells, the water table was found to be closer to the ground surface, especially in areas of Assagao and near Bodgeshwar temple. The reason for the higher water level could be due to groundwater flowing from places of higher elevation such as Ghateshwar Nagar to places of lower elevation such as Assagao and Bogeshwar temple.

Towards the NE direction, the hydraulic conductivity is constant, as depicted by steep equipotential lines. However, the overall hydraulic conductivity in

Mapusa City was found to be steady and gentle which is demonstrated by the evenly spaced equipotential lines.

Further, it was noticed that in the North and Northwest direction, the groundwater depicted a higher hydraulic head. Whereas, in the South and Southeast direction, the groundwater depicted a lower hydraulic head due to variations in the elevations.

At last, it was observed that the groundwater flow was passing through the agricultural and industrial areas. As a consequence, most of the wells in the city had acidic or extreme basic pH and higher EC which was might have caused due to agricultural run-off.

CHAPTER 05: CHEMICAL ANALYSIS

5.1 INTRODUCTION

To investigate the groundwater quality, it is crucial to analyze the physiochemical parameters of the water which are divided into physical parameters that include pH, Electrical Conductivity, Total Dissolved Solids, and chemical parameters that include Total Hardness, Calcium, Magnesium, Sodium, and Potassium ions.

Through these parameters, we can infer the overall groundwater quality for drinking and irrigation purposes which are easily affected by urbanization, extensive agriculture, improper municipal waste dumps, population rise, over-exploitation of groundwater, and industrial dumps.

The natural causes for the poor quality of groundwater are mainly lithology, weathering of soils, level of Carbon Dioxide, decaying of organic matter, accumulation of dust particles, and presence of Carbonate rocks aquifers.

5.2 PHYSICAL PARAMETERS

5.2.1 pH

The pH of groundwater samples can change due to several reasons such as the geology of the region, contaminants, and the environment. The higher pH is caused due to lower carbon dioxide concentration and the lower pH is caused due to higher concentration of carbon dioxide. As per the Bureau of Indian Standards (BIS) (2012), groundwater has a pH between 6.5 to 8.5 which corresponds to slightly acidic, neutral, and slightly basic.

Observation:

The pH of 15 well water samples was analyzed in December. The pH data was plotted on the base map as shown in Figure 5.3, wherein the variation in the pH was studied. The exact pH value of each well sample is given in Table 5.8. Only one well was found to be basic i.e. Well 4 with pH value 9.9. The rest of the well water samples showed a slightly acidic nature as per the permissible limits laid by the BIS (Bureau of Indian Standards (BIS) (2012). The average pH value was between 5.8. The variation was studied using Figure 5.4.

Two wells were found to be close to the neutral range, Well 2 and Well 7 wherein the pH values were 6.1 and 6.61 respectively. Well 1, Well 3, Well 5, Well 6, Well 8, Well 9, Well 10, Well 11, Well 12, Well 13, Well 14, and Well 15 showed a slightly acidic nature wherein the pH value range was between 5.2 to 5.61.

Table 5.8: pH of the wells

WELL ID	LATITUDE (DECIMAL)	LONGITUDE (DECIMAL)	pH
1	15.5844540	73.8059550	5.37
2	15.5925160	73.8068000	6.20
3	15.5972810	73.8166730	5.57
4	15.5969050	73.8001690	9.90
5	15.6007500	73.8272370	5.61
6	15.6003200	73.8179070	5.54
7	15.6031700	73.8242330	6.61
8	15.6025290	73.8153970	5.42
9	15.6115820	73.8138350	5.39
10	15.6140660	73.8142520	5.40
11	15.6163030	73.8153120	5.45
12	15.6118000	73.8051200	5.26
13	15.6122000	73.8102300	5.54
14	15.5900570	73.8124250	5.30
15	15.5910833	73.8205000	5.31

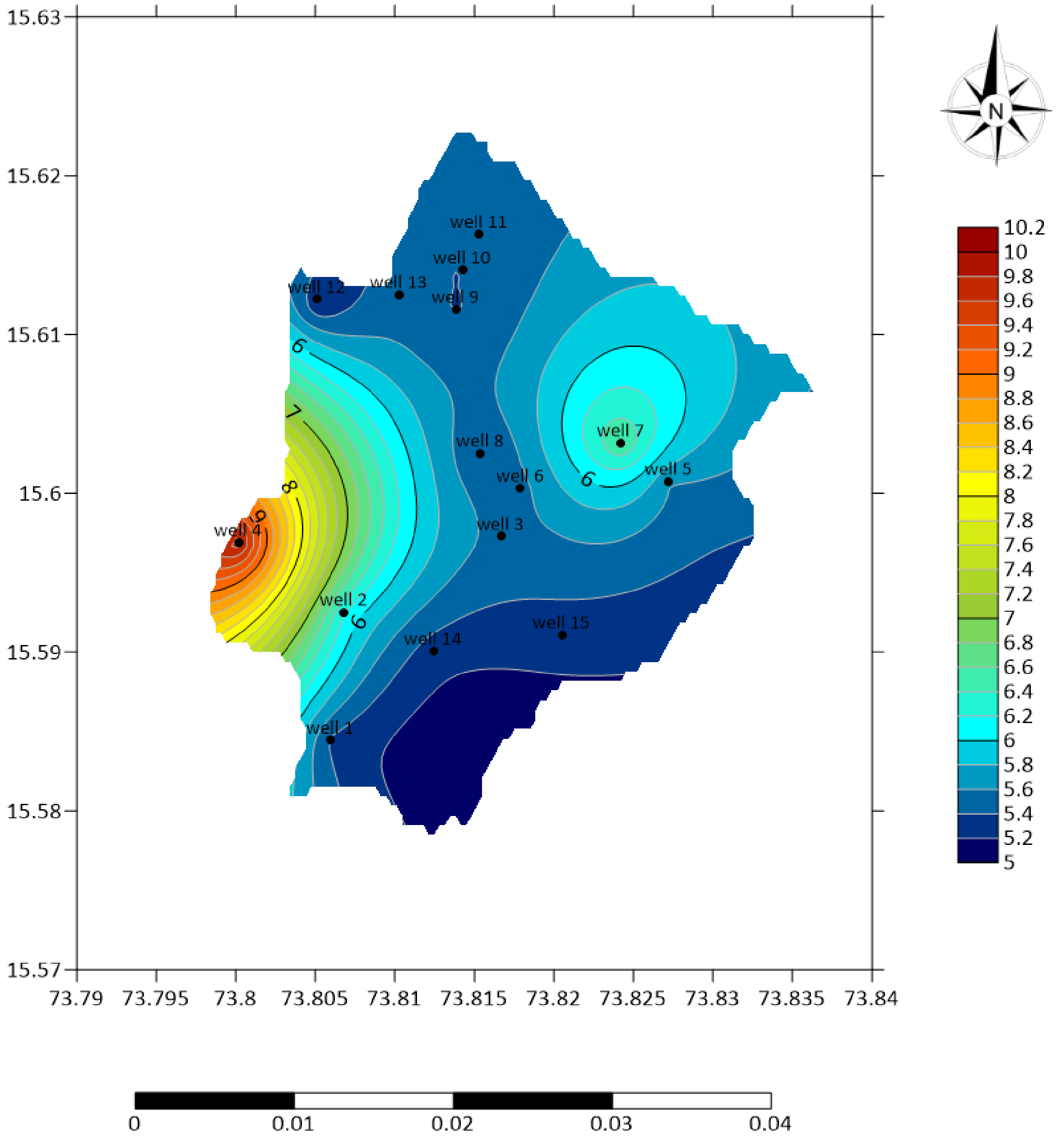

Figure 5.3: Contour Distribution of the pH

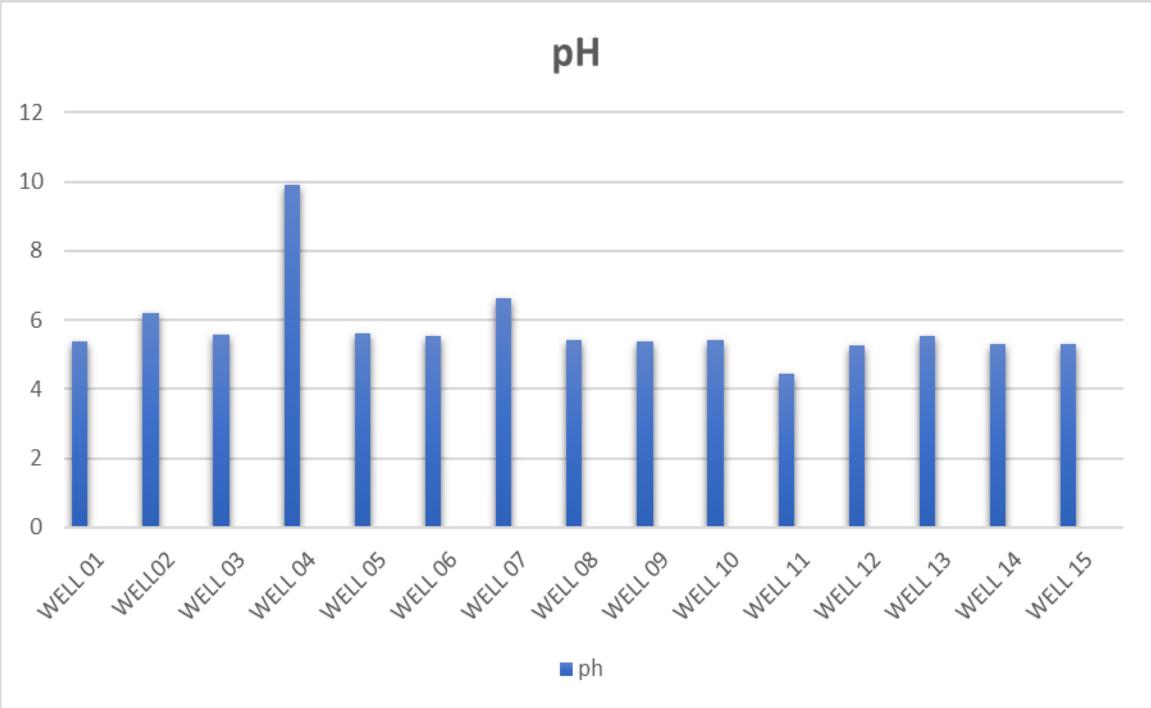

Figure 5.4: Graph illustrating variation in pH

Inference:

Only one well was within the range laid by the Bureau of Indian Standards (BIS) (2012) which was Well 7 with a pH value of 6.6. The slightly acidic nature was seen in the following wells, Well 1, Well 3, Well 5, Well 6, well 7, Well 8, Well 9, Well 10, Well 11, Well 12, Well 13, Well 14, and Well 15. The well water samples were collected in post-monsoons as a consequence that the pH might have become acidic as rainfall increases oxygen availability leading to the formation of acidic compounds, rainfall can carry acidic substances from the soil surface into the groundwater, rainfall can absorb Carbon Dioxide from the atmosphere which forms carbonic acid. The alkaline nature of Well 4 with a pH value of 9.9 could be explained by the depth of the well i.e. 9.15m, long residence time, and limited oxygen availability which in turn slows down the oxidation of minerals and reduces the formation of acidic compounds. Acidic water can be corrosive and lead to the leaching of heavy metals such as Fe, Cu, and Mn.

5.2.2 ELECTRICAL CONDUCTIVITY

The Electrical Conductivity is expressed as microSiemens per centimeter (µS/cm) and millliSiemens per centimeter (mS/cm). Electrical Conductivity shows a direct relation with Total Dissolved Solids, wherein, higher Electrical Conductivity corresponds to higher Total Dissolved Solids and lower Electrical Conductivity corresponds to lower Total Dissolved Solids. The Electrical Conductivity can be used to deduce the locations of contamination in an aquifer of an area. As per WHO (World Health Organization) (2007) guidelines, Electrical Conductivity should not be more than 400 µS/cm of water that is used for drinking purposes. However, the Electrical Conductivity in the range between 750-2000 µS/cm is considered for irrigation purposes (Tutmez et al. 2006).

Observation:

The EC of 15 well water samples was analyzed in December. The pH data was plotted on the base map as shown in Figure 5.5, wherein the variation in the EC values was studied. The exact EC value of each well sample is given in Table 5.9. Figure 5.6 depicts variations in the EC values of groundwater samples.

As per the BIS (2012), Well 2, Well 3, Well 5, Well 6, Well 7, Well 8, and Well 9 were within the permissible limits for drinking water purposes. However, well 1, Well 4, Well 10, Well 11, Well 12, Well 13, Well 14, and Well 15 were unfit for drinking purposes, rather these were within the permissible limits for irrigation purposes.

Table 5.9: Electrical Conductivity of the wells

WELL ID	LATITUDE (DECIMAL)	LONGITUDE (DECIMAL)	ELECTRICAL CONDUCTIVITY (μS/cm)
1	15.5844540	73.8059550	975
2	15.5925160	73.8068000	94
3	15.5972810	73.8166730	112
4	15.5969050	73.8001690	1080
5	15.6007500	73.8272370	108
6	15.6003200	73.8179070	105
7	15.6031700	73.8242330	151
8	15.6025290	73.8153970	99
9	15.6115820	73.8138350	202
10	15.6140660	73.8142520	1192
11	15.6163030	73.8153120	1065
12	15.6118000	73.8051200	979
13	15.6122000	73.8102300	1113.4
14	15.5900570	73.8124250	1175
15	15.5910833	73.8205000	1150

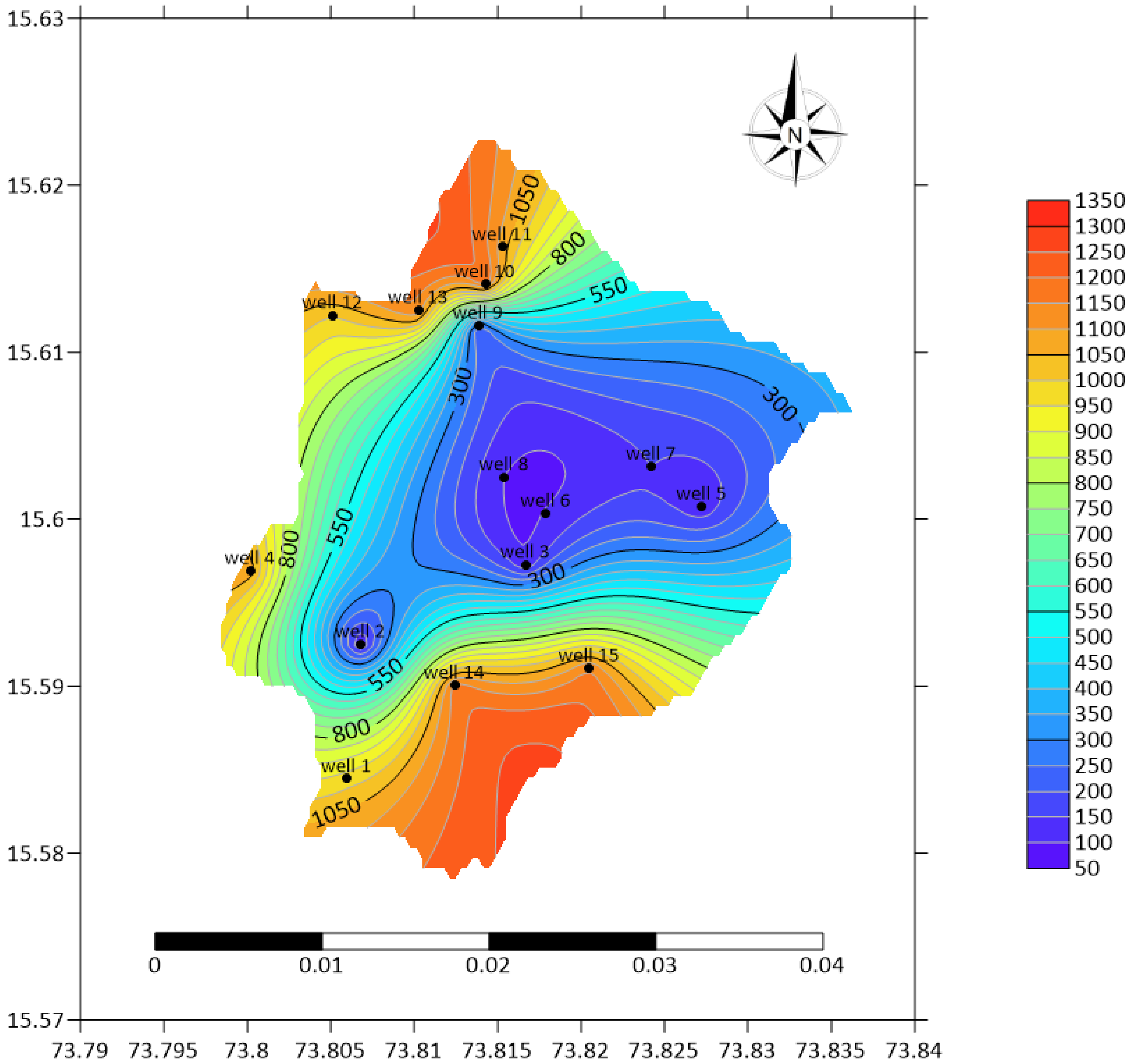

Figure 5.5: Contour Distribution of the Electrical Conductivity

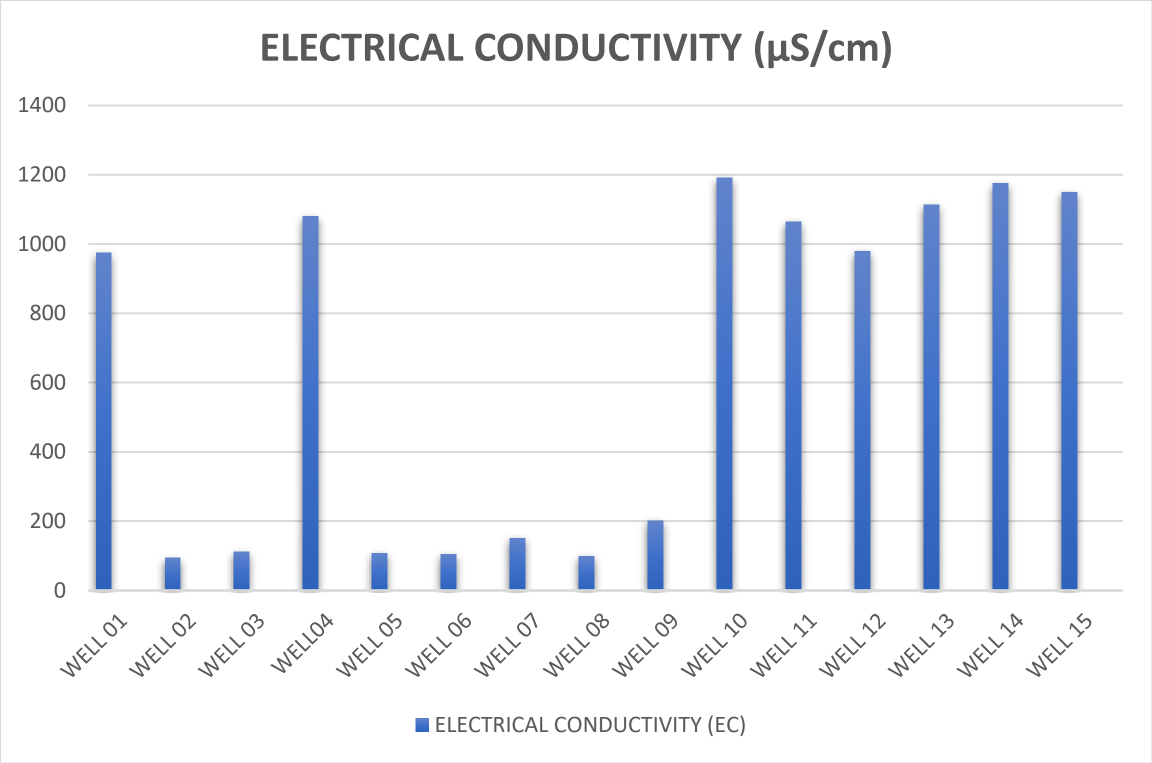

Figure 5.6: Graph illustrating variation in the Electrical Conductivity

Inference:

As per the BIS (2012), Well 2, Well 3, Well 5, Well 6, Well 7, Well 8, and Well 9 were within the permissible limits for drinking water purposes. Figure 5.10 shows variation in the EC values. However, well 1, Well 4, Well 10, Well 11, Well 12, Well 13, Well 14, and Well 15 show higher values for Electrical Conductivity could be because of several reasons such as agricultural activities, the interaction between aquifer water and wastewater discharge, dissolved ions, decaying of organic matter such as leaf and stems, presence of soil particles and soil microbes.

5.2.3 TOTAL DISSOLVED SOLIDS

The Total Dissolved Solids are expressed as milligrams per liter (mg/L). Low Total Dissolved Solids are generally considered good-quality water, however high TDS is normal in groundwater due to the aquifer's geology and hydrological properties. The high Total Dissolved Solids are caused by several reasons such as the interaction between aquifer water and wastewater discharge, dissolved salts, and runoff from irrigational areas. The increase in TDS concentration is reduced by a technique known as Reverse Osmosis. As per BIS (2012), TDS up to 500 mg/L value is a desirable limit for drinking purposes, and for irrigation purposes, the permissible limit is up to 2000 mg/L.

Observations:

The TDS of well water samples were analyzed in December. The TDS was plotted on the base map as shown in Figure 5.7, wherein the variation in the TDS values was studied. The exact TDS value of each well sample is given in Table 5.10. Figure 5.8 depicts variations in the TDS values of groundwater samples

As per the acceptable limits laid by BIS (2012), Well 2, Well 3, Well 5, Well 6, Well 7, Well 8, and Well 9 are suitable for drinking purposes. Whereas, Well 1, Well 4, well 10, Well 11, Well 12, Well 13, Well 14, and Well 15 are above the acceptable limits.

Table 5.10: Total Dissolved Solids in the wells

WELL ID	LATITUDE (DECIMAL)	LONGITUDE (DECIMAL)	TOTAL DISSOLVED SOLIDS (mg/L)
1	15.5844540	73.8059550	624.00
2	15.5925160	73.8068000	60.00
3	15.5972810	73.8166730	71.68
4	15.5969050	73.8001690	691.2
5	15.6007500	73.8272370	69.12
6	15.6003200	73.8179070	67.20
7	15.6031700	73.8242330	96.64
8	15.6025290	73.8153970	63.36
9	15.6115820	73.8138350	129.28
10	15.6140660	73.8142520	762.88
11	15.6163030	73.8153120	681.60
12	15.6118000	73.8051200	626.56
13	15.6122000	73.8102300	712.58
14	15.5900570	73.8124250	752.00
15	15.5910833	73.8205000	736.00

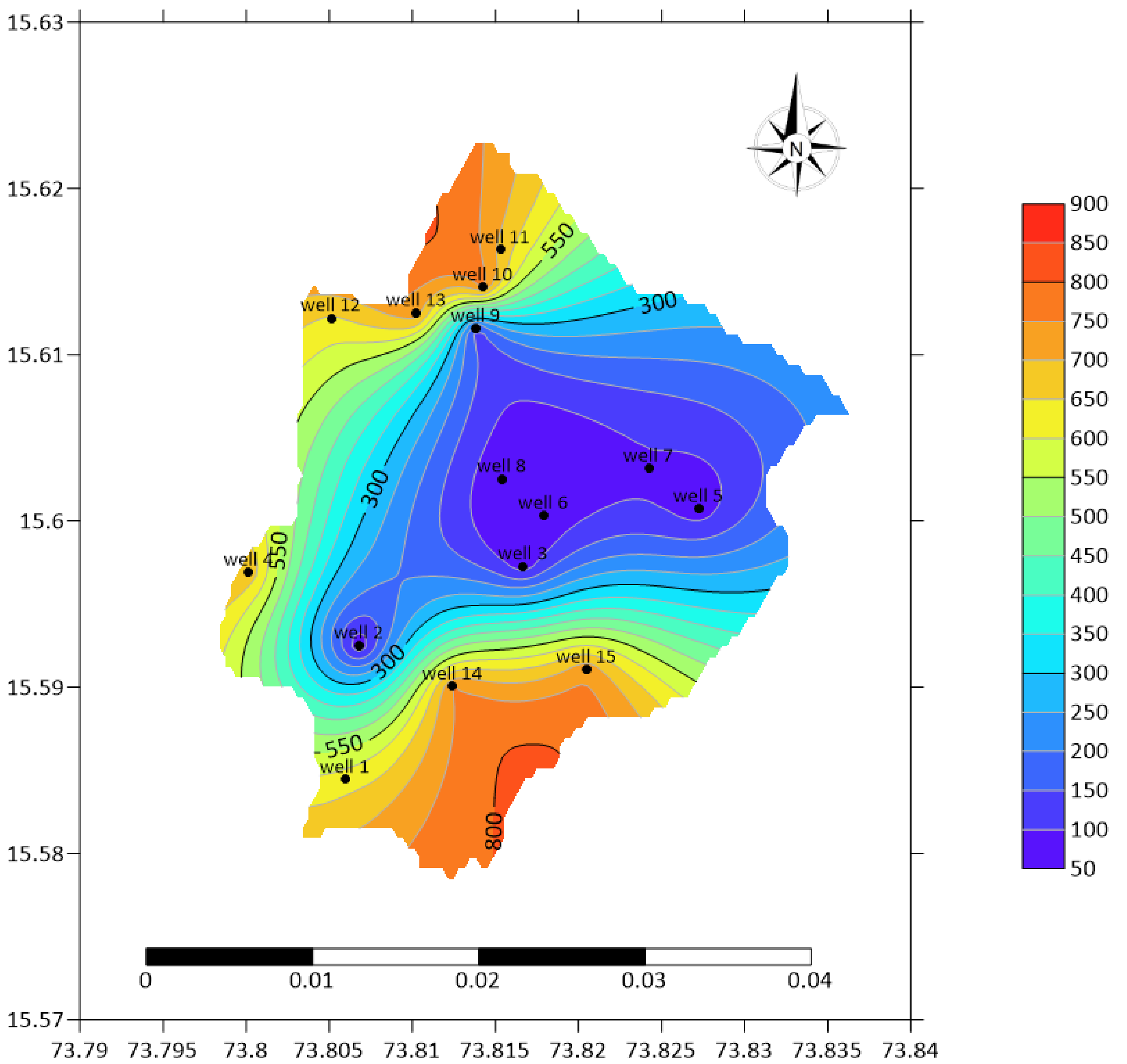

Figure 5.7: Contour Distribution of Total Dissolved Solids

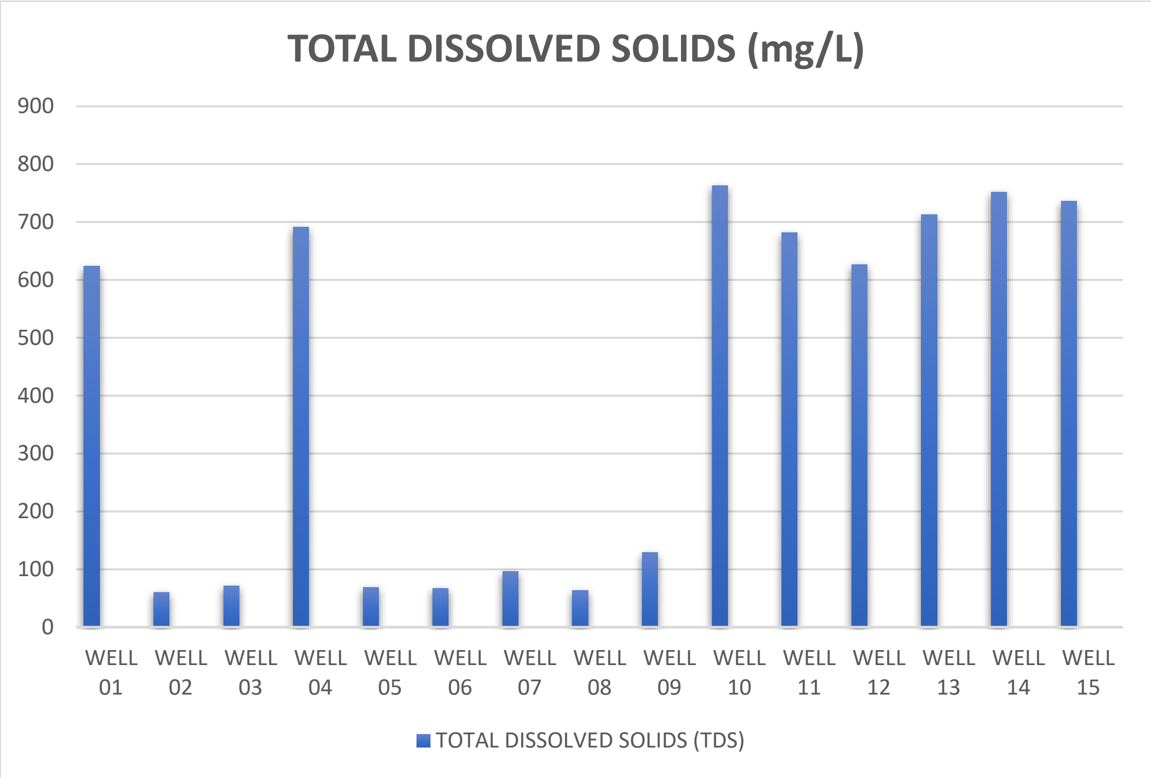

Figure 5.8: Graph illustrating variation in Total Dissolved Solids

Inference:

The Well 2, Well 3, Well 5, Well 6, Well 7, Well 8, and Well 9 are suitable for drinking purposes. Whereas, Well 1, Well 4, well 10, Well 11, Well 12, Well 13, Well 14, and Well 15 had Total Dissolved Solid values higher than 500mg/L which could have connections to intense agricultural activities, dissolved solids, decaying organic matter, soil particles, soil microbes, and interaction of aquifer with wastewater discharge.

5.3 CHEMICAL PARAMETERS

5.3.1 TOTAL HARDNESS

The Total Hardness is expressed as milligrams per liter (mg/L) and it is irreversible by boiling. Total Hardness is determined by the concentration of multivalent cations in water such as Mg+2 and Ca2+. The Total Hardness is the summation of Calcium and Magnesium concentration. The water hardness is mainly caused by to weathering of Carbonate-bearing rocks. The Carbonate hardness is a result of carbonate and bicarbonate hardness. The Magnesium Chloride, Magnesium Sulfate, and Calcium Chloride salts contribute to non-carbonate hardness. The summation of carbonate and non-carbonate gives us total hardness. As per BIS (2012), the permissible limit for Total Hardness is 200 mg/L for drinking purposes. The wells with their respective total hardness are given in Table 5.11 and Figure 5.10 compares the Total Hardness. The variation in the Total Hardness is depicted in Figure 5.9.

Inference:

It is found that Well 9 and Well 10 water samples are moderately hard with a Total Hardness of 80 mg/L and 120 mg/L respectively as the range given by Vetrimurugan at el. (2013). All the remaining Well water samples are soft with a range of 28 mg/L to 72 mg/L.

The Well 9 and Well 10 are moderately hard due to the presence of Magnesium, Calcium, and other dissolved metals that are leached due to weathering of the Laterite.

Table 5.11: Total Hardness of the wells

WELL ID	LATITUDE (DECIMAL)	LONGITUDE (DECIMAL)	TOTAL HARDNESS (mg/L)
1	15.5844540	73.8059550	32
2	15.5925160	73.8068000	32
3	15.5972810	73.8166730	32
4	15.5969050	73.8001690	36
5	15.6007500	73.8272370	28
6	15.6003200	73.8179070	32
7	15.6031700	73.8242330	40
8	15.6025290	73.8153970	56
9	15.6115820	73.8138350	80
10	15.6140660	73.8142520	120
11	15.6163030	73.8153120	28
12	15.6118000	73.8051200	32
13	15.6122000	73.8102300	48
14	15.5900570	73.8124250	60
15	15.5910833	73.8205000	72

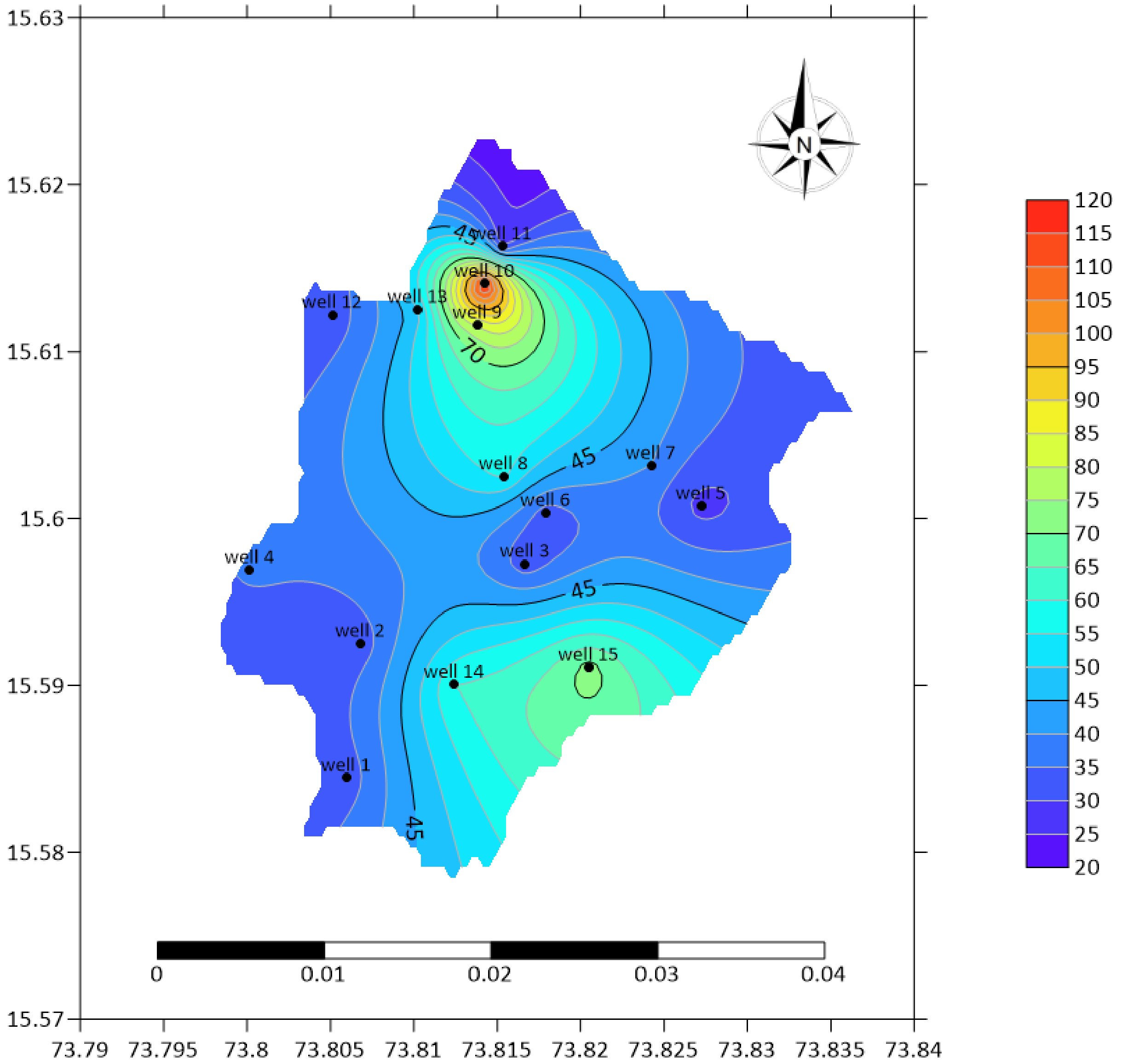

Figure 5.9: Contour Distribution of Total Hardness

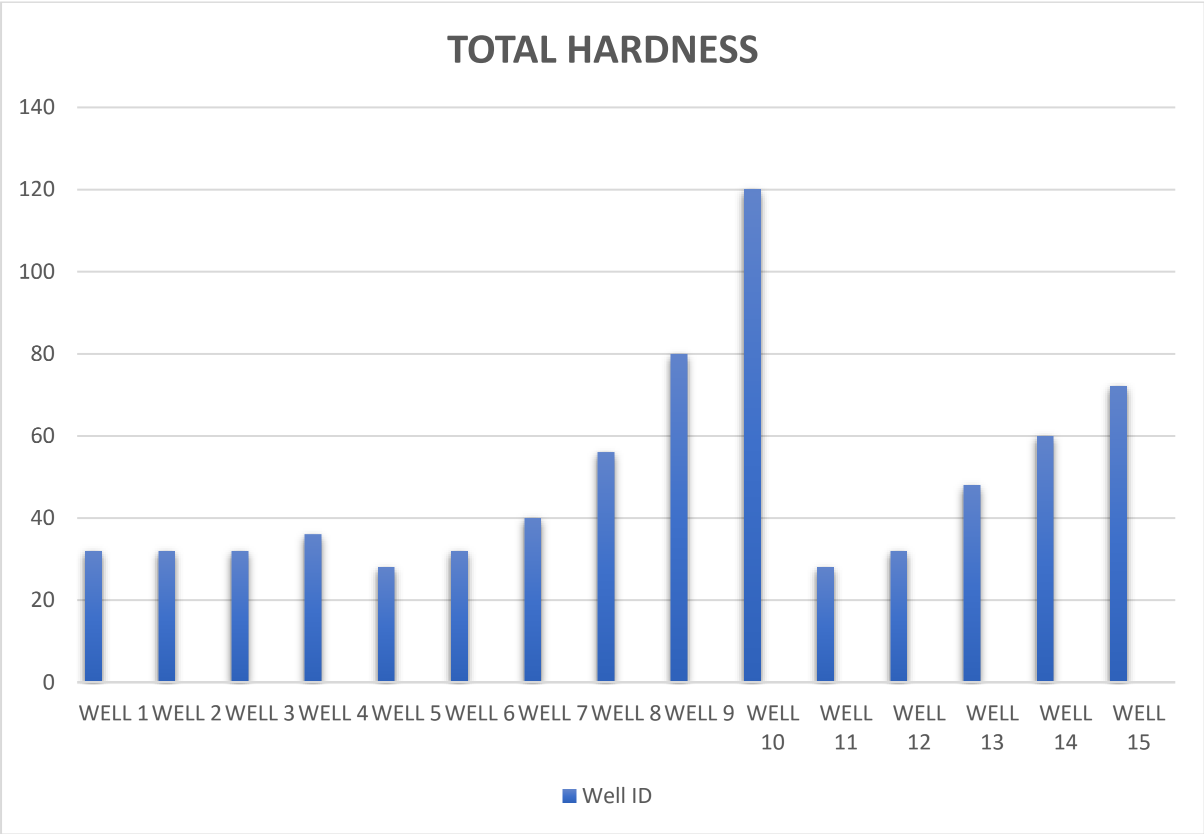

Figure 5.10: Graph illustrating variation in Total Hardness

5.3.2 CALCIUM CONCENTRATION

Calcium is one of the major cations in the crust of the Earth and groundwater. It is normally found in the bones and shells of aquatic life. It can also come from the weathering of rocks containing calcium such as Limestone and Marble. As per BIS (2012), 75mg/L is the acceptable limit when the water is considered soft. Calcium hardness is expressed as milligrams per liter (mg/L). The wells with their respective calcium concentration are given in Table 5.12. Figure 5.11 and Figure 5.12 show the variation in Calcium Hardness.

Inference:

All the samples are below the acceptable limit of Calcium concentration in groundwater as per BIS (2012). The Calcium concentration of the wells ranges from 4.8 mg/L to 22.4 mg/L.

The low concentration of Calcium indicates that there are no Calcium-rich rocks around the aquifer.

Table 5.12: Calcium Concentration of the wells

WELL ID	LATITUDE (DECIMAL)	LONGITUDE (DECIMAL)	CALCIUM (Ca), (mg/L)
1	15.5844540	73.8059550	6.40
2	15.5925160	73.8068000	6.40
3	15.5972810	73.8166730	6.40
4	15.5969050	73.8001690	4.80
5	15.6007500	73.8272370	6.40
6	15.6003200	73.8179070	4.80
7	15.6031700	73.8242330	12.80
8	15.6025290	73.8153970	8.00
9	15.6115820	73.8138350	16.00
10	15.6140660	73.8142520	22.40
11	15.6163030	73.8153120	8.00
12	15.6118000	73.8051200	6.40
13	15.6122000	73.8102300	8.00
14	15.5900570	73.8124250	17.60
15	15.5910833	73.8205000	14.40

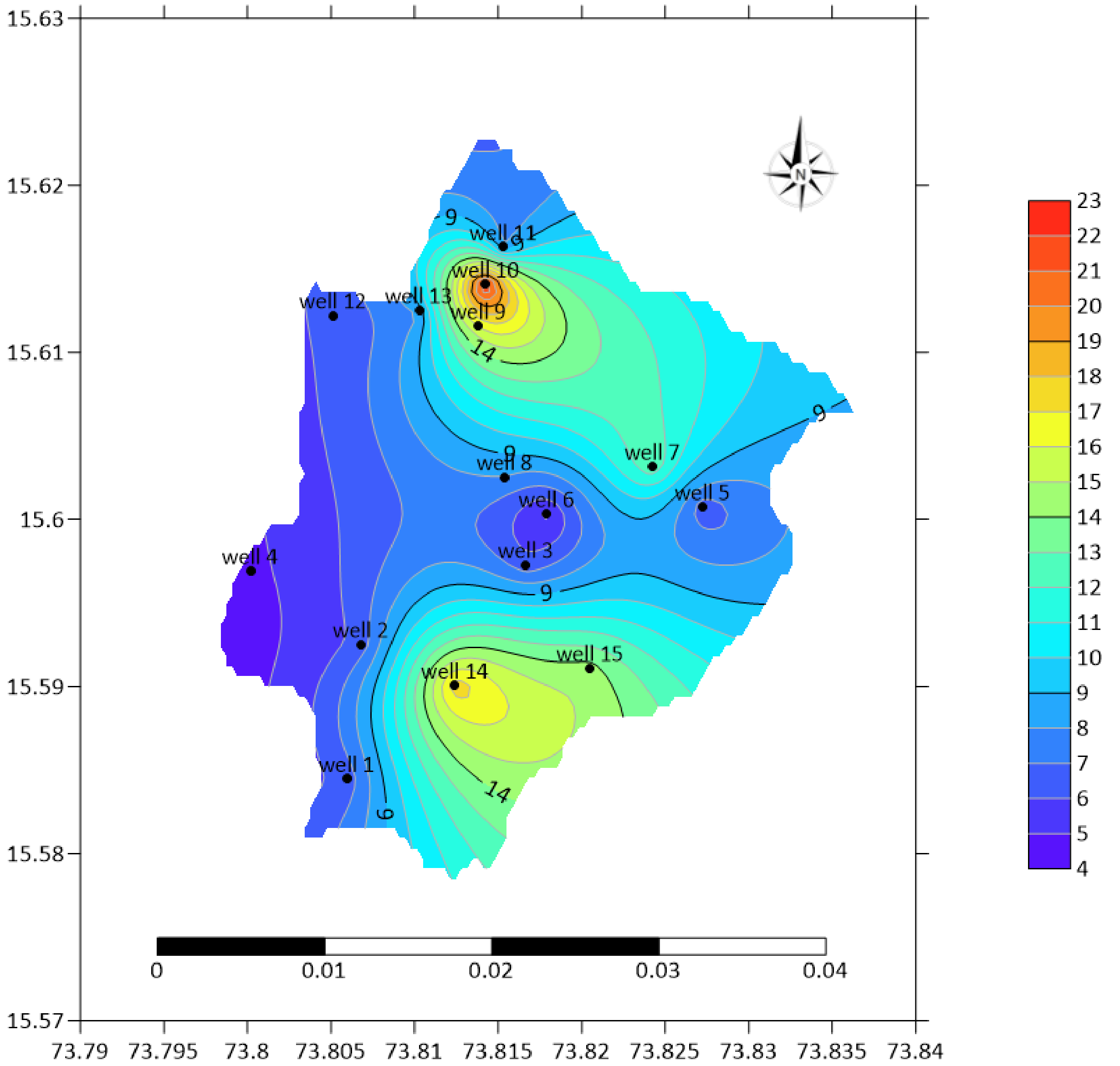

Figure 5.11: Contour Distribution of Calcium Concentration

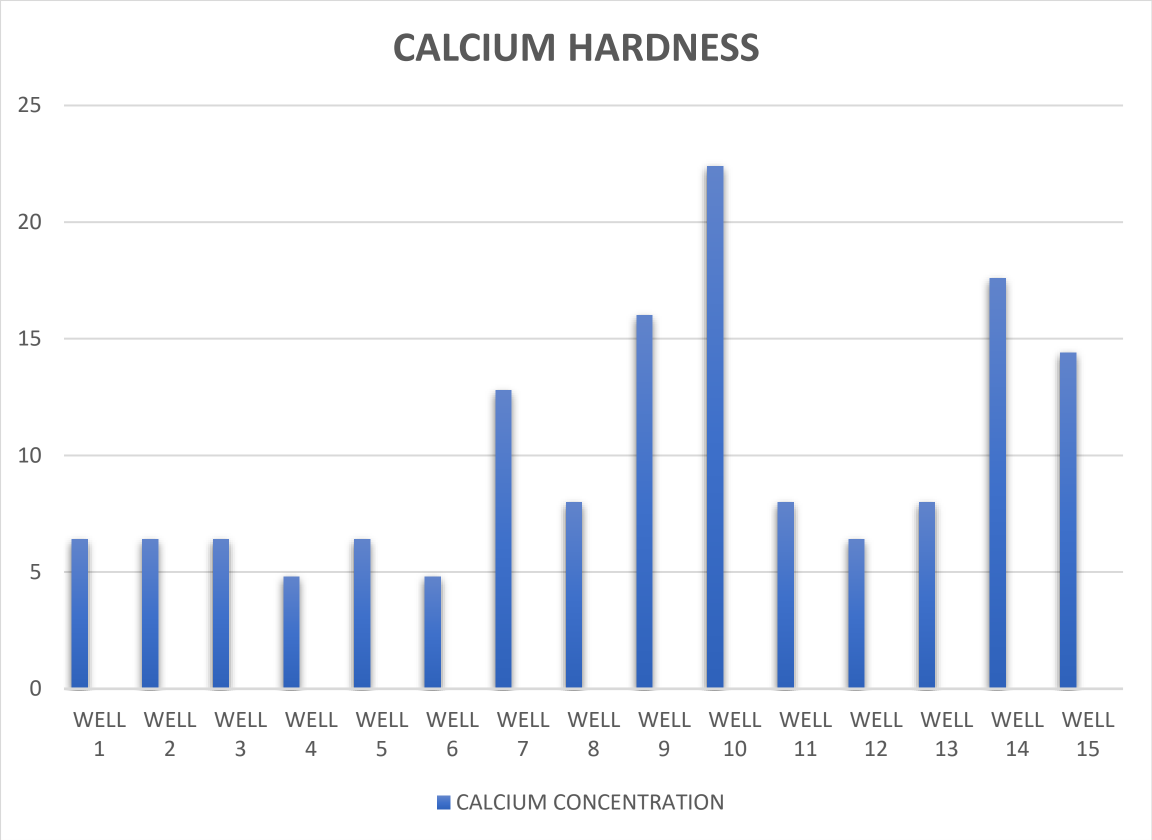

Figure 5.12: Graph illustrating variation in Calcium Concentration

5.3.3 MAGNESIUM CONCENTRATION

Magnesium in groundwater usually gets leached out from magnesium-containing rocks. The minerals such as Amphiboles, Pyroxenes, Olivines, and Micas contain a significant amount of Magnesium in their structure in the form of Mg+2. This Magnesium can also make its pathway through municipal waste such as plastics and agricultural products like fertilizers. As per BIS (2012) limits states Magnesium hardness up to 100mg/L is allowable, however, the recommended limit is 30mg/L. The Wells with their respective Magnesium hardness are given in Table 5.13 and Figure 13 and Figure 5.14 illustrate the variation in the Magnesium hardness.

Inference:

All the well water samples were within the permissible limit laid by BIS (2012). Well 1, Well 2, Well 3, Well 5, Well 6, Well 7, Well 11, and Well 12 were within the recommended limit i.e. 30 mg/L. However, Well 4, Well 8, Well 9, Well 10, Well 13, Well 14, and Well 15 were above the recommended limit which might be due to weathering of Laterites.

Table 5.13: Magnesium Concentration of the wells

WELL ID	LATITUDE (DECIMAL)	LONGITUDE (DECIMAL)	MAGNESIUM (Mg), (mg/L)
1	15.5844540	73.8059550	25.60
2	15.5925160	73.8068000	25.60
3	15.5972810	73.8166730	25.60
4	15.5969050	73.8001690	31.20
5	15.6007500	73.8272370	21.60
6	15.6003200	73.8179070	27.20
7	15.6031700	73.8242330	27.20
8	15.6025290	73.8153970	48.00
9	15.6115820	73.8138350	64.00
10	15.6140660	73.8142520	97.60
11	15.6163030	73.8153120	20.00
12	15.6118000	73.8051200	25.60
13	15.6122000	73.8102300	40.00
14	15.5900570	73.8124250	42.40
15	15.5910833	73.8205000	57.60

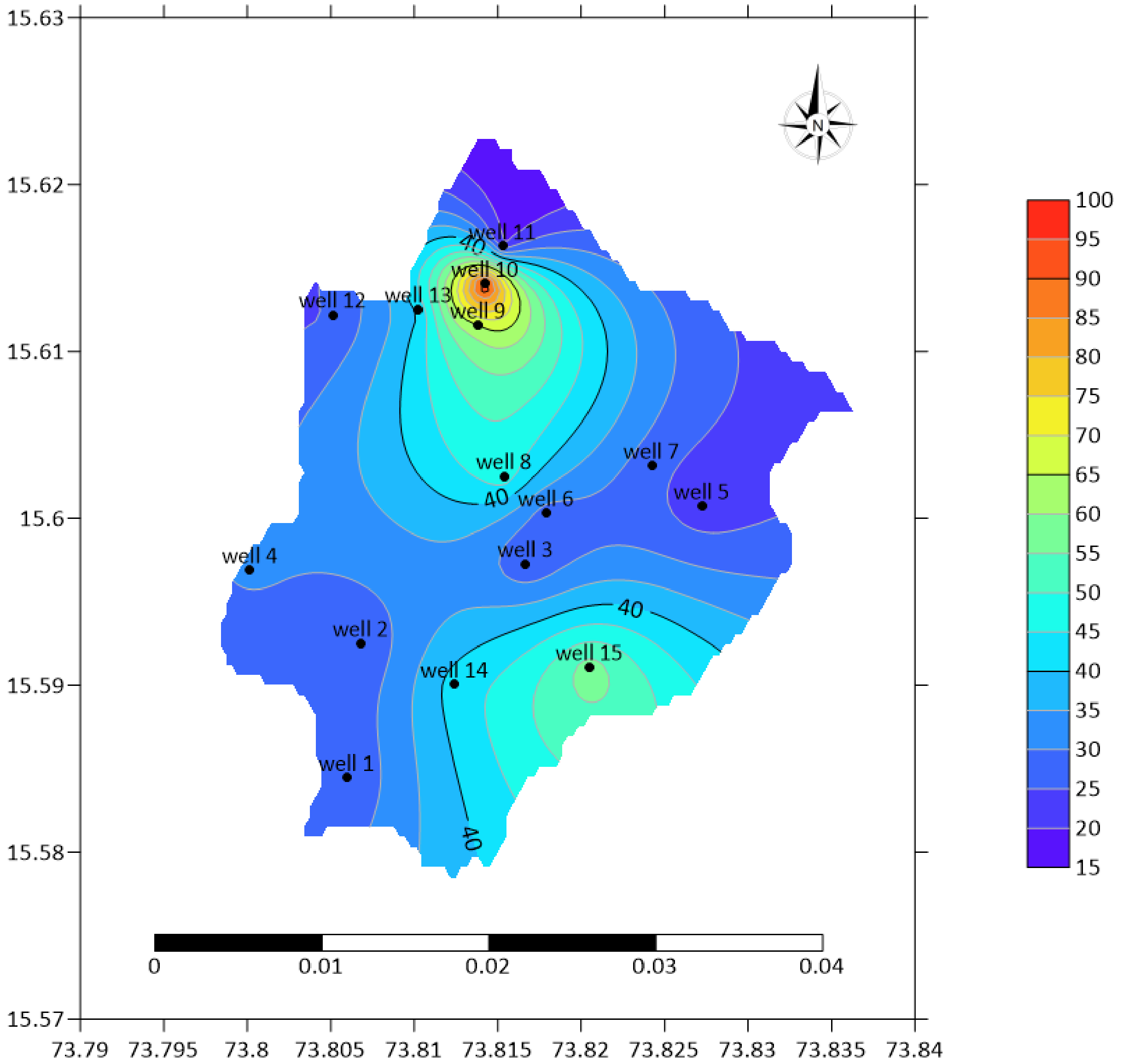

Figure 5.13: Contour Distribution of Magnesium Concentration

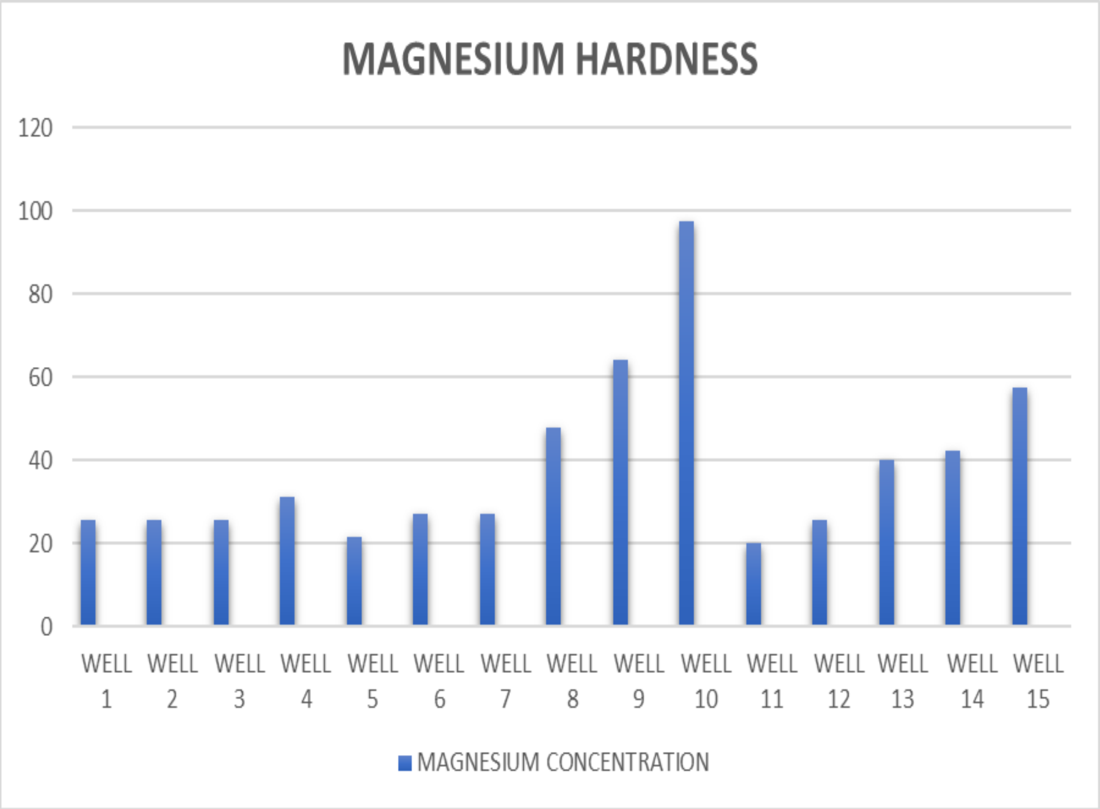

Figure 5.14: Graph illustrating variation in Magnesium Concentration

5.3.4 SODIUM CONCENTRATION

Sodium is one of the major cations in the Earth's crust. It is readily found in rocks and soils. The Sodium can seep into the groundwater through various pathways such as sewage discharge, industrial discharge, agricultural runoff of fertilizers and pesticides, and water softener discharge. Sodium is usually present as salts in coastal areas. Mainly, Sodium concentration increases in groundwater due to extensive irrigation and use of fertilizers. Sodium is vital in some quantities for the healthy functioning of the human body. As per the WHO (World Health Organization) (2006), the permissible limit for Sodium concentration in drinking water is 200 mg/L. The well samples with their respective Sodium concentration are given in Table 5.14 and Figure 5.15 and Figure 5.16 illustrates the variation in Sodium concentration in groundwater samples.

Inference:

All the well water samples are within the permissible limit laid by WHO (2006). The Sodium concentration in wells varies from 4.9 ppm to 23.1 ppm. The average value of Sodium concentration in groundwater samples is 12.8 ppm. The low concentration of Sodium indicates that these are freshwater samples. The Well 9, Well 7, Well 4, Well 14, and Well 15 show slightly high Sodium concentrations which might be due to the agricultural inputs.

Table 5.14: Sodium Concentration of the wells

WELL ID	LATITUDE (DECIMAL)	LONGITUDE (DECIMAL)	SODIUM (Na), (PPM)
1	15.5844540	73.8059550	4.90
2	15.5925160	73.8068000	11.70
3	15.5972810	73.8166730	13.80
4	15.5969050	73.8001690	23.10
5	15.6007500	73.8272370	5.50
6	15.6003200	73.8179070	12.50
7	15.6031700	73.8242330	20.10
8	15.6025290	73.8153970	10.30
9	15.6115820	73.8138350	25.90
10	15.6140660	73.8142520	13.80
11	15.6163030	73.8153120	5.30
12	15.6118000	73.8051200	7.20
13	15.6122000	73.8102300	17.20
14	15.5900570	73.8124250	21.70
15	15.5910833	73.8205000	20.20

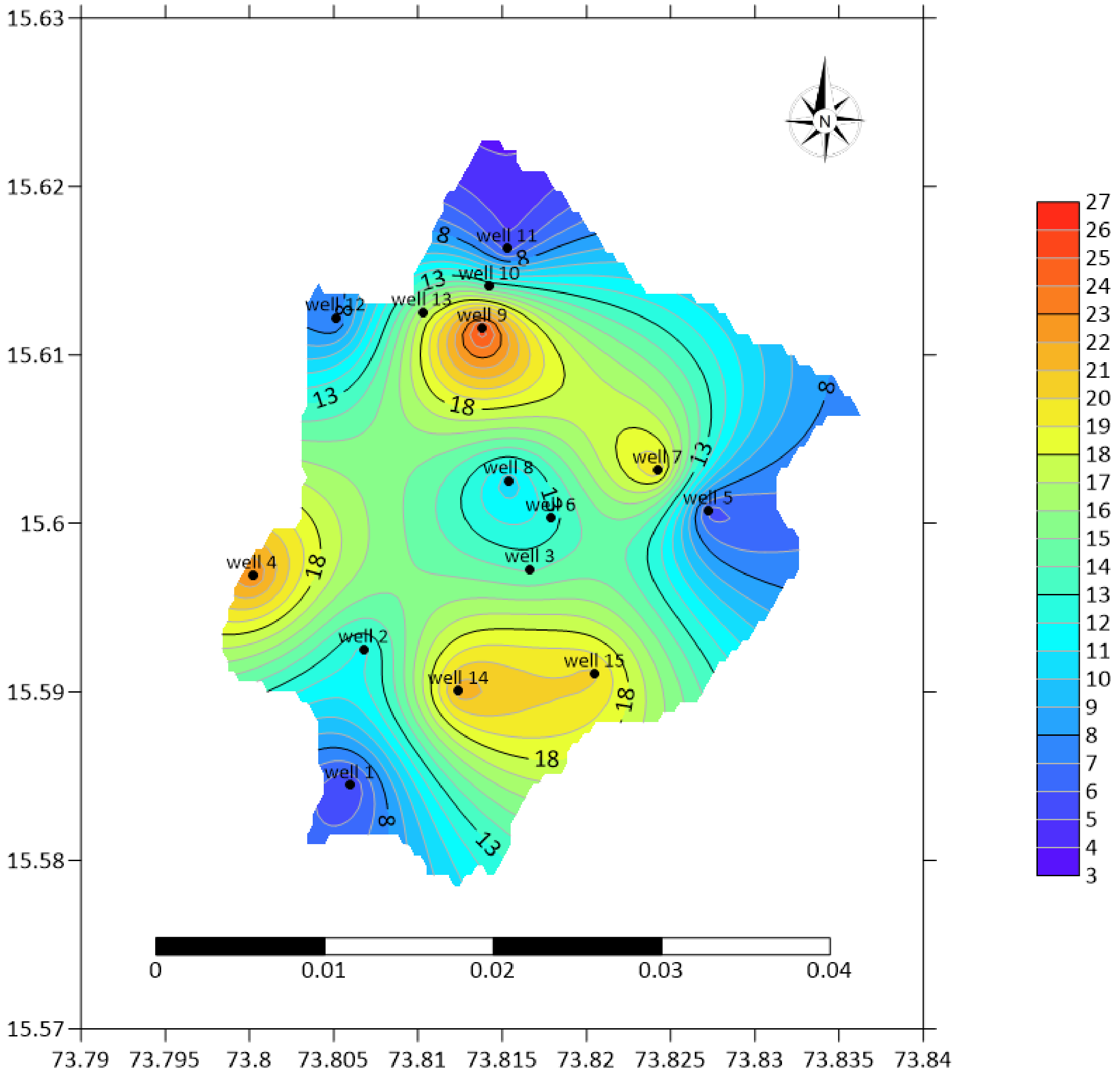

Figure 5.15: Contour Distribution of Sodium Concentration

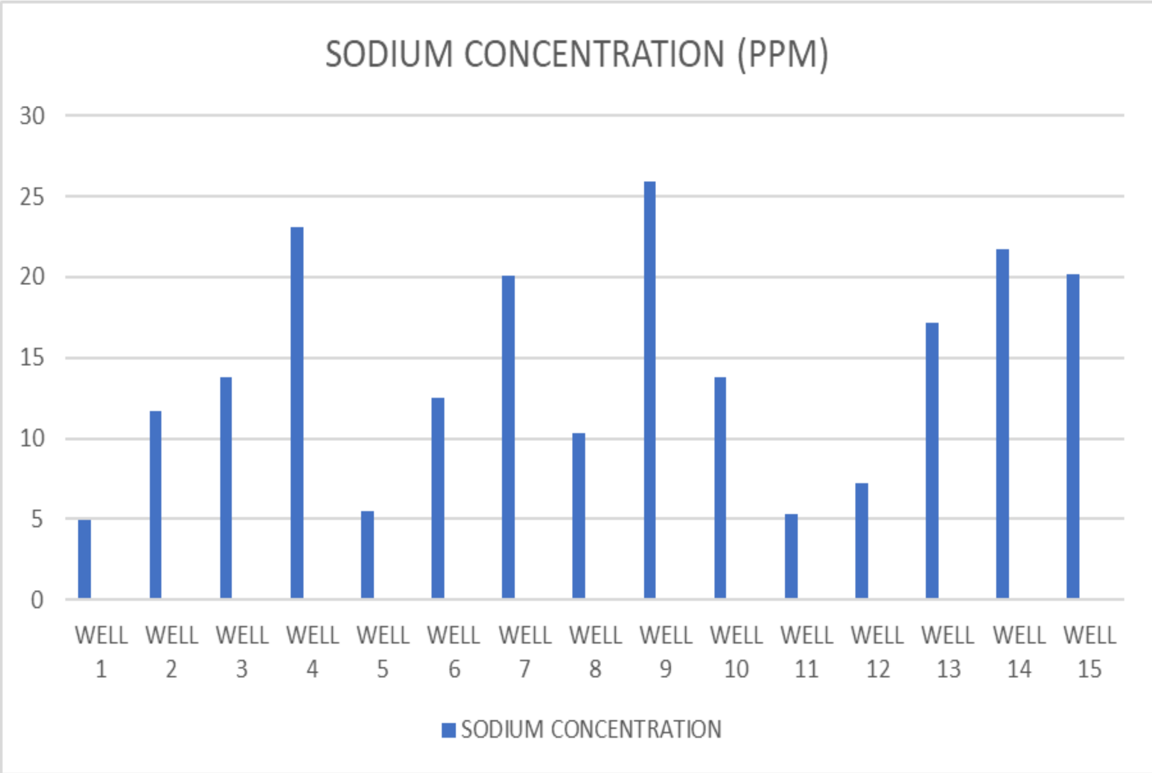

Figure 5.16: Graph illustrating variation in the Sodium Concentration

5.3.5 POTASSIUM CONCENTRATION

Potassium presence in high quantities in groundwater can indicate potential spots of contamination. The Potassium concentration can increase in groundwater through anthropogenic and natural sources. The anthropogenic sources include sewage discharge, industrial discharge, and agricultural runoff of fertilizers and pesticides. The natural sources include weathering of Potassium-containing clay minerals and rocks containing Potassium-rich minerals such as Orthoclase and Microcline. The leakage of sewer pipes and Septic tanks can contribute to Potassium concentration in groundwater. Animal excreta which contain plants which is rich in Potassium. High dosage of Potassium can lead to kidney-related issues in humans. Water softeners used in wells to reduce the hardness of water can contribute to high Potassium concentration in groundwater. As per WHO (2006), the permissible for Potassium in drinking water is 55 mg/L. The wells with their respective Potassium concentration are given in Table 5.15, Figure 5.17, and Figure 5.18 illustrating the variation in the Potassium concentration in groundwater samples.

Inference:

All the samples are within the permissible limit laid by WHO (2006) for drinking water. The Potassium concentration varies from 2.6 ppm to 39.5 ppm. The average value of Potassium concentration in the groundwater is 10.4 ppm. The sudden increase in Potassium concentration in Well 5 and Well 7 i.e. 39.5 ppm and 23.3 ppm may be caused due to water cleaning agents which contain Potassium in high amounts. Table 5.15 contains wells with their corresponding Potassium concentration.

Table 5.15: Potassium Concentration of the wells

WELL ID	LATITUDE (DECIMAL)	LONGITUDE (DECIMAL)	POTASSIUM (K), (PPM)
1	15.5844540	73.8059550	3.40
2	15.5925160	73.8068000	4.70
3	15.5972810	73.8166730	7.40
4	15.5969050	73.8001690	14.30
5	15.6007500	73.8272370	39.50
6	15.6003200	73.8179070	9.20
7	15.6031700	73.8242330	23.30
8	15.6025290	73.8153970	4.10
9	15.6115820	73.8138350	8.30
10	15.6140660	73.8142520	5.10
11	15.6163030	73.8153120	2.60
12	15.6118000	73.8051200	3.10
13	15.6122000	73.8102300	8.50
14	15.5900570	73.8124250	13.10
15	15.5910833	73.8205000	9.50

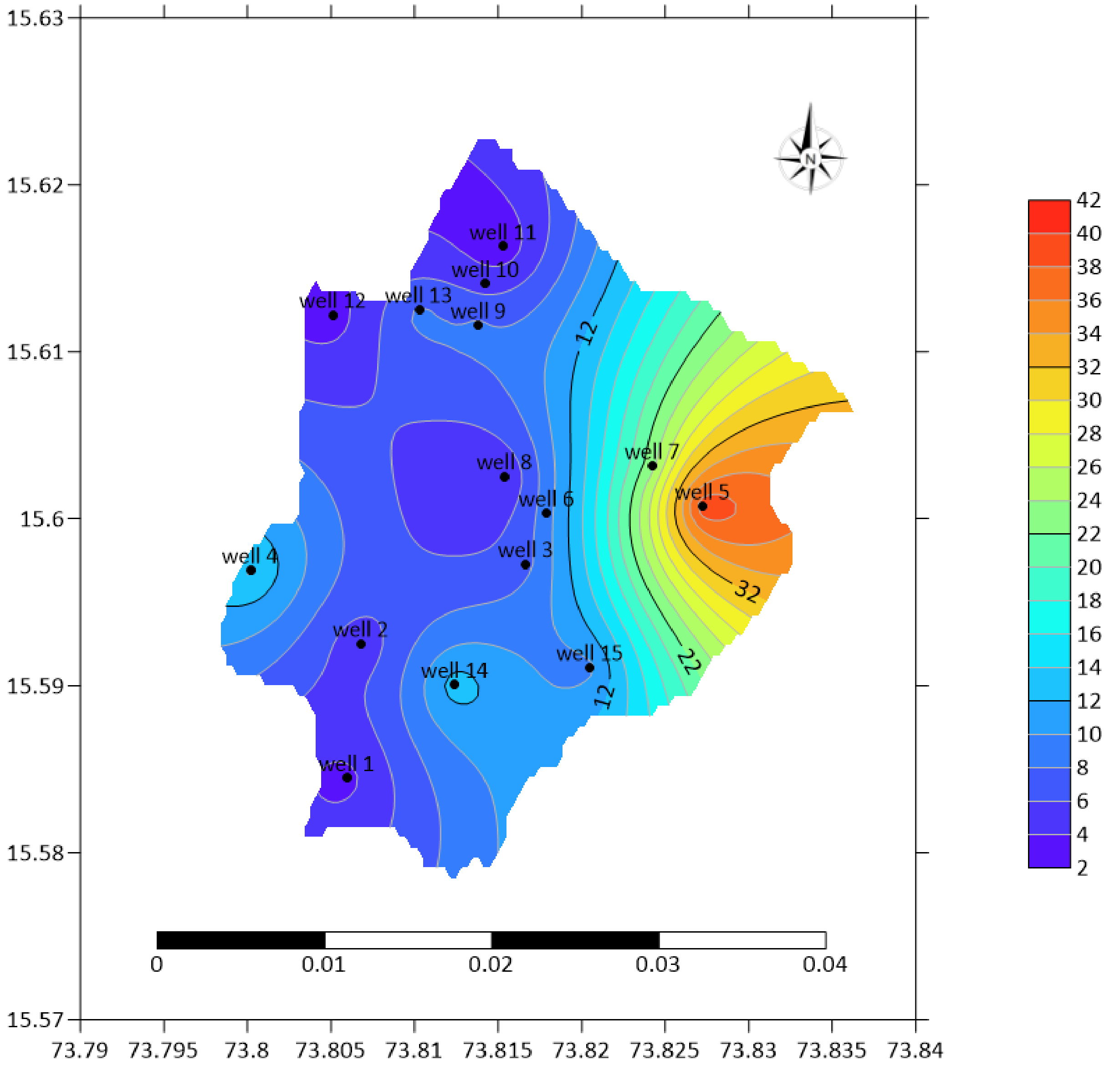

Figure 5.17: Contour Distribution of Potassium Concentration

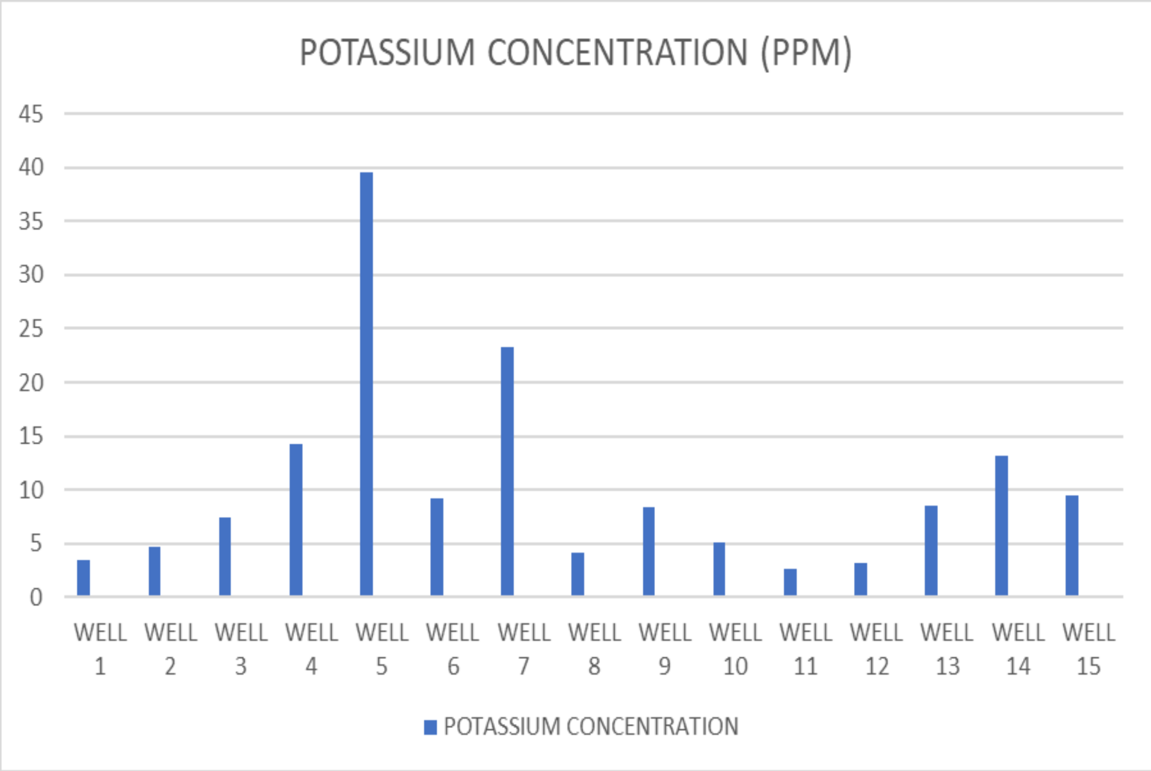

Figure 5.18: Graph illustrating variation in the Potassium Concentration

CHAPTER 06: HPI, MI, & WQI OBSERVATIONS

REPORT OF HEAVY METALS IN WELL WATER SAMPLES (ICAR)

भाकृअनुप - केन्द्रीय तटीय कृषि अनुसंधान संस्थान

भारतीय कृषि अनुसंधान परिषद

ICAR- CENTRAL COASTAL AGRICULTURAL RESEARCH INSTITUTE

Indian Council of Agricultural Research

F. No. ICAR-CCARI /NRM/SS/2023

Date: 05/04/2024

To,
Mahesh Mayekar,
Assistant Professor Goa University, Bambolim, Goa.

Name and address	: Mahesh Mayekar, Assistant Professor Goa University, Bambolim Goa.
Mobile Number	: 9158851415
Sample received on	: 23/02/2024
Sample described as	: Water
Parameters to be analyzed	: Mentioned in table below
Stamped by/Seal	: -
ID mark	: Mentioned in table
Laboratory where analyzed	: Soil Science Laboratory, Section, NRM ICAR-CCARI, Old Goa. 403402-Goa.

Test Report

No.	Sample ID	Parameter (Unit)			
		Iron (ppm)	Manganese (ppm)	Copper (ppm)	Zinc (ppm)
1	SC W-1	0.3057	ND	ND	0.0955
2	SC W-3	0.2701	ND	ND	0.1024
3	SC W-4	0.2076	ND	ND	0.0891
4	SC W-7	0.1247	ND	ND	0.1124
5	SC W-9	0.4617	ND	ND	0.0911
6	SC W-10	0.1481	0.7865	ND	0.0752
7	SC W-11	0.1163	ND	ND	0.0889
8	SC W-12	0.2430	ND	ND	0.1340
9	SC W-13	0.4265	ND	ND	0.1069
10	SC W-14	0.2332	ND	ND	0.0987
11	SC W -15	0.3301	ND	ND	0.092
12	SG W -1	1.1580	0.6096	ND	0.1449
13	SG W-2	0.2285	ND	ND	0.1043
14	SG W-3	0.0836	ND	ND	0.1670
15	SG W-5	0.1225	ND	ND	0.1759
16	SG W-7	0.1101	ND	ND	0.1772
17	SG W-8	0.7093	0.3925	ND	0.1328
18	SG W-10	0.3679	ND	ND	0.2282
19	SG W-11	0.2339	ND	ND	0.1545
20	SG W-12	2.1060	2.7910	ND	0.2007
21	SG W-13	0.2352	ND	ND	0.1821
22	SG W-14	0.2770	0.0902	ND	0.1547

Note: ppm – parts per million; ND- Non Detectable.

SAMPLE(S) NOT DRAWN BY
ICAR-CCARI, OLD GOA, GOA

Dr. Gopal R. Mahajan
Sr. Scientist (Soil Science)

वरिष्ठ वैज्ञानिक (मृदा विज्ञान)
Senior Scientist (Soil Science)
विभाग - प्राकृतिक संसाधन प्रबंधन
Section - Natural Resource Management
ICAR – Central Coastal Agricultural Research Institute
Ela, Old Goa 403402, Goa, India

Note:

- Test results are related only to the sample(s) tested.
- The ICAR-CCARI is not responsible for the authenticity of the photocopied or computer scanned copy of this report.
- Samples will be retained by ICAR-CCARI for a period of 30 days after issue of the report, unless specific instructions to the contrary are received.
- No handwritten entries except signature and manual corrections are made in this report.

Disclaimer: The analysis report provided should not be used as a proof for any legal/commercialization / advertisement /certification related aspects.

Figure 6.19: ICAR Report of Heavy Metals

(SC ID Samples are of this study)

Table 6.16: Fe, Zn, Mn, & Cu Concentration in ppm

WELL ID	LATITUDE (DECIMAL)	LONGITUDE (DECIMAL)	Fe (PPM)	Zn (PPM)	Mn (PPM)	Cu (PPM)
1	15.5844540	73.8059550	0.3057	0.0955	ND	ND
3	15.5972810	73.8166730	0.2701	0.1024	ND	ND
4	15.5969050	73.8001690	0.2076	0.0891	ND	ND
7	15.6031700	73.8242330	0.1247	0.1124	ND	ND
9	15.6115820	73.8138350	0.4617	0.0911	ND	ND
10	15.6140660	73.8142520	0.1481	0.0752	0.7865	ND
11	15.6163030	73.8153120	0.1163	0.0889	ND	ND
12	15.6118000	73.8051200	0.2430	0.1340	ND	ND
13	15.6122000	73.8102300	0.4265	0.1069	ND	ND
14	15.5900570	73.8124250	0.2332	0.0987	ND	ND
15	15.5910833	73.8205000	0.3301	0.0920	ND	ND

6.1 HEAVY METAL POLLUTION INDEX (HPI)

Table 6.17: Heavy Metal Pollution Index

HEAVY METALS	SYMBOL	WELL 01	WELL 03	WELL 04	WELL 07	WELL 09	WELL 10	WELL 11	WELL 12	WELL 13	WELL 14	WELL 15
IRON	Fe	0.76	4.00	12.37	23.48	21.66	4.93	24.60	7.63	16.94	8.95	4.03
ZINC	Zn	3.07	3.06	3.07	3.05	3.07	0.75	3.07	3.04	3.06	3.06	3.07
MANGANESE	Mn	0	0	0	0	0	259.65	0	0	0	0	0
OVERALL HPI		3.83	7.07	15.44	26.53	24.72	265.3	27.67	10.68	20.00	12.00	7.10
SAFE/CRITICAL (<100, >100)		SAFE	SAFE	SAFE	SAFE	SAFE	CRITICAL	SAFE	SAFE	SAFE	SAFE	SAFE
LOW/MEDIUM/HIGH (0-15), (15-30), (>30)		LOW	LOW	MED.	MED.	MED.	HIGH	MED.	LOW	MED.	LOW	LOW

Observation:

Table 6.17 shows the HPI values of individual heavy metals along with the overall HPI value of each well. Based on its HPI value the well water samples are assigned with a tag as safe and critical water. Further, the well water samples are also divided into low, medium, and high ranges of heavy metals based on the HPI value calculated for that respective well. Table 6.16 and Figure 6.19 show the concentration of Fe, Zn, Mn, and Cu.

Only one well water sample was found to be critical and unsafe for drinking purposes as per the Heavy Metal Pollution Index i.e. Well no. 10. In Well 10 Fe, Zn, and Mn concentration combined was found to be high, wherein the Manganese was found to be a major contributor of heavy metal contamination in the well. The overall heavy metal index number was 265.3 of Well 10.

The Well 4, Well 7, Well 9, Well 11, and Well 13 had medium levels of heavy metal contamination as per the HPI. Furthermore, Well 1, Well 3, Well 4, Well 7, Well 8, Well 9, Well 11, Well 12, Well l3, Well 14, and Well 15 water was found to be safe for drinking purposes as far as the heavy metals concentration is concerned. Well 1, Well 3, Well 12, Well 14, and Well 15 had low levels of heavy metal contamination as per the Heavy Metal Pollution Index, Figure 6.20 illustrates the no. of wells found to have low, medium, and high levels of heavy metal contamination. Figure 6.21 and Figure 6.27 displays the variation in HPI in well water samples.

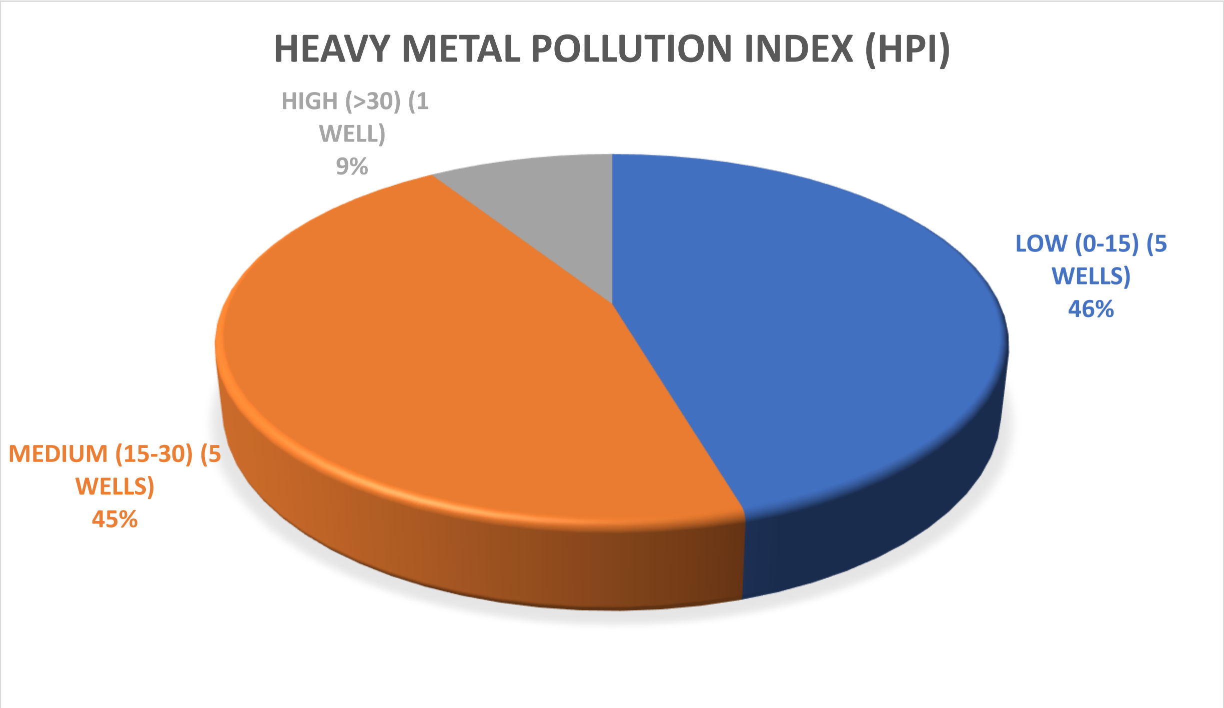

Figure 6.20: Pie Chart depicting the no. of wells of each category as per HPI

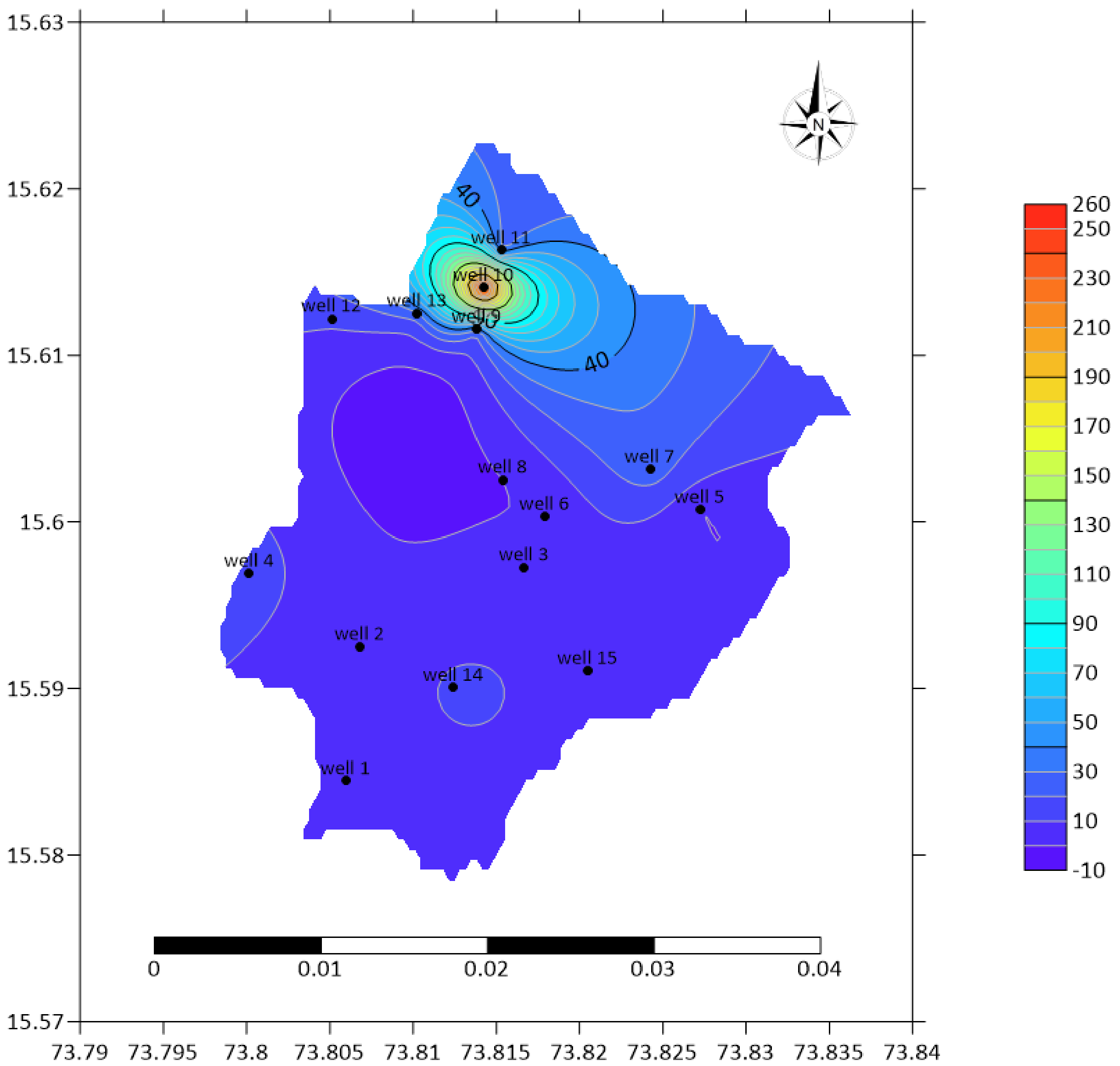

Figure 6.21: Contour Distribution of Heavy Metal Pollution Index Values

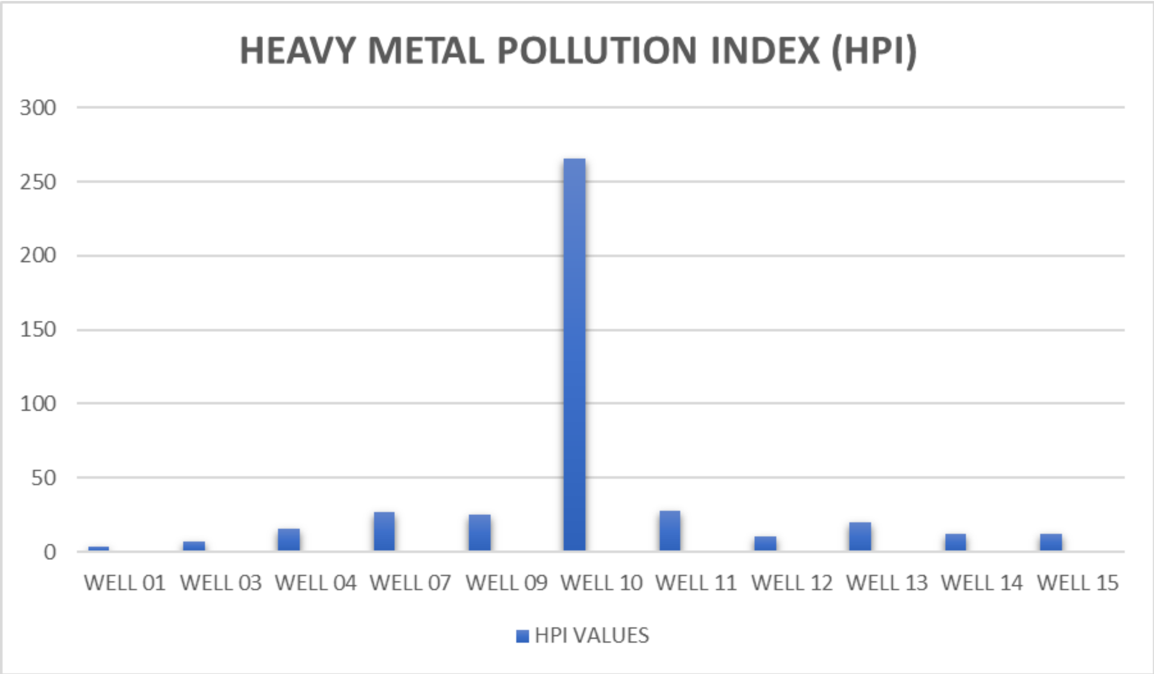

Figure 6.27: Graph depicting variation in the Heavy Metal Pollution Index Values

Inference:

The high levels of Manganese contamination in Well 10 might be due to the infiltration of sewage during the rainy seasons into the groundwater, wherein, there was an abandoned toilet in the vicinity of 10m. All the other wells had low levels of heavy metals, which suggests that they were safe for drinking purposes as far as tested heavy metal concentration was concerned.

6.2 METAL INDEX (MI)

Table 6.18: Metal Index

HEAVY METALS	SYMBOL	WELL 01	WELL 03	WELL 04	WELL 07	WELL 9	WELL 10	WELL 11	WELL 12	WELL 13	WELL 14	WELL 15
IRON	Fe	0.31	0.27	0.21	0.12	0.46	0.15	0.12	0.24	0.42	0.23	0.33
ZINC	Zn	0.01	0.01	0.01	0.01	0.01	0.05	0.01	0.01	0.01	0.01	0.01
MANGANESE	Mn	0	0	0	0	0	2.62	0	0	0	0	0
OVERALL MI		0.31	0.28	0.21	0.13	0.47	2.82	0.12	0.25	0.43	0.24	0.34
INFERENCE		PURE	VERY PURE	VERY PURE	VERY PURE	PURE	MODERATELY AFFECTED	VERY PURE	VERY PURE	PURE	VERY PURE	PURE
CLASS		II	I	I	I	II	IV	I	I	II	I	II

Observation:

Table 6.18 illustrates the MI value of each heavy metal present in that respective well along with its overall MI value. Based on the calculated MI value the well water samples were assigned to a class which ranges from Class I to Class VI which had a corresponding inference.

As per the Metal Index, only one well was moderately affected by heavy metal contamination. Whereas, all the other wells were pure and safe for drinking purposes. The overall MI of Well 10 was 2.62 wherein the Manganese was the major contributor to heavy metal contamination in the groundwater. As per MI classification, the Well 10 water sample was categorized with class IV.

The Well 1, Well 9, Well 13, and Well 15 were categorized with class II and which is considered to be safe water for drinking purposes as per MI. Furthermore, Well 3, Well 4, Well 7, Well 11, Well 12, and Well 14 had very low concentrations of heavy metals and the samples were regarded as very pure for drinking purposes as far as heavy metal concentration is concerned. Figure 6.28 illustrates the no. of wells found to be very pure, pure, and moderately affected by heavy metal contamination as per MI. Figure 6.29 and Figure 6.30

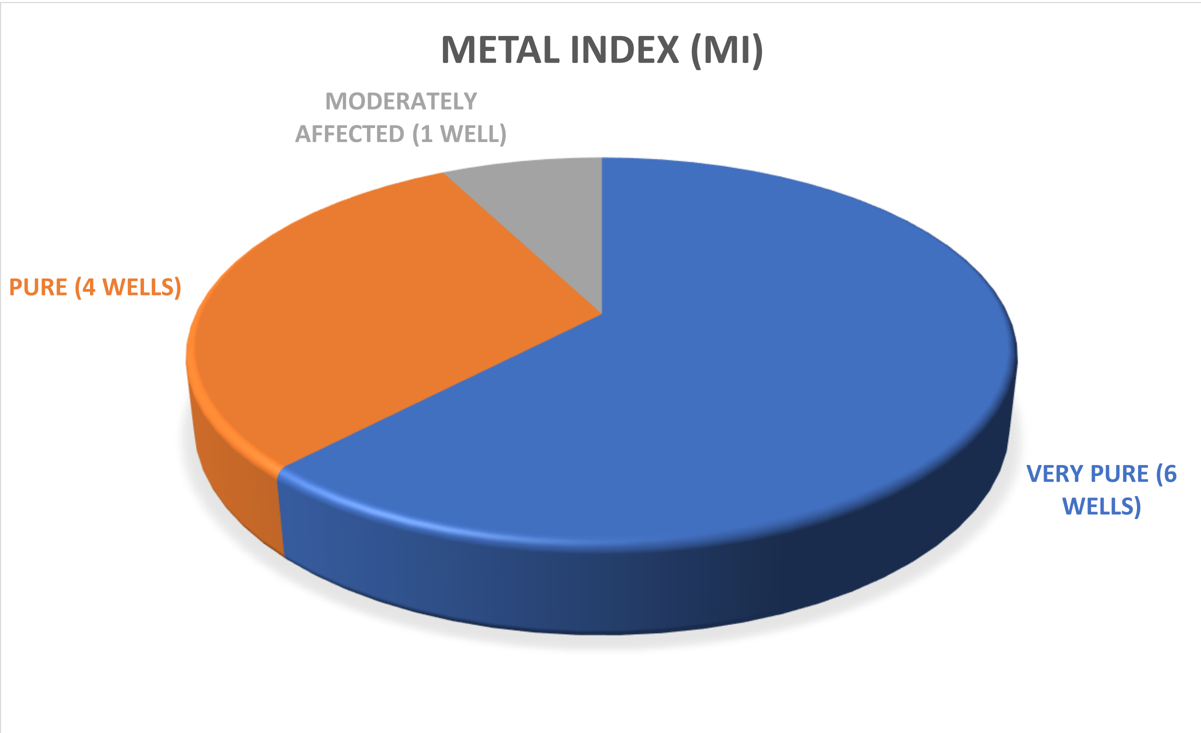

Figure 6.28: Pie Chart depicting the no. of wells of each category as per MI

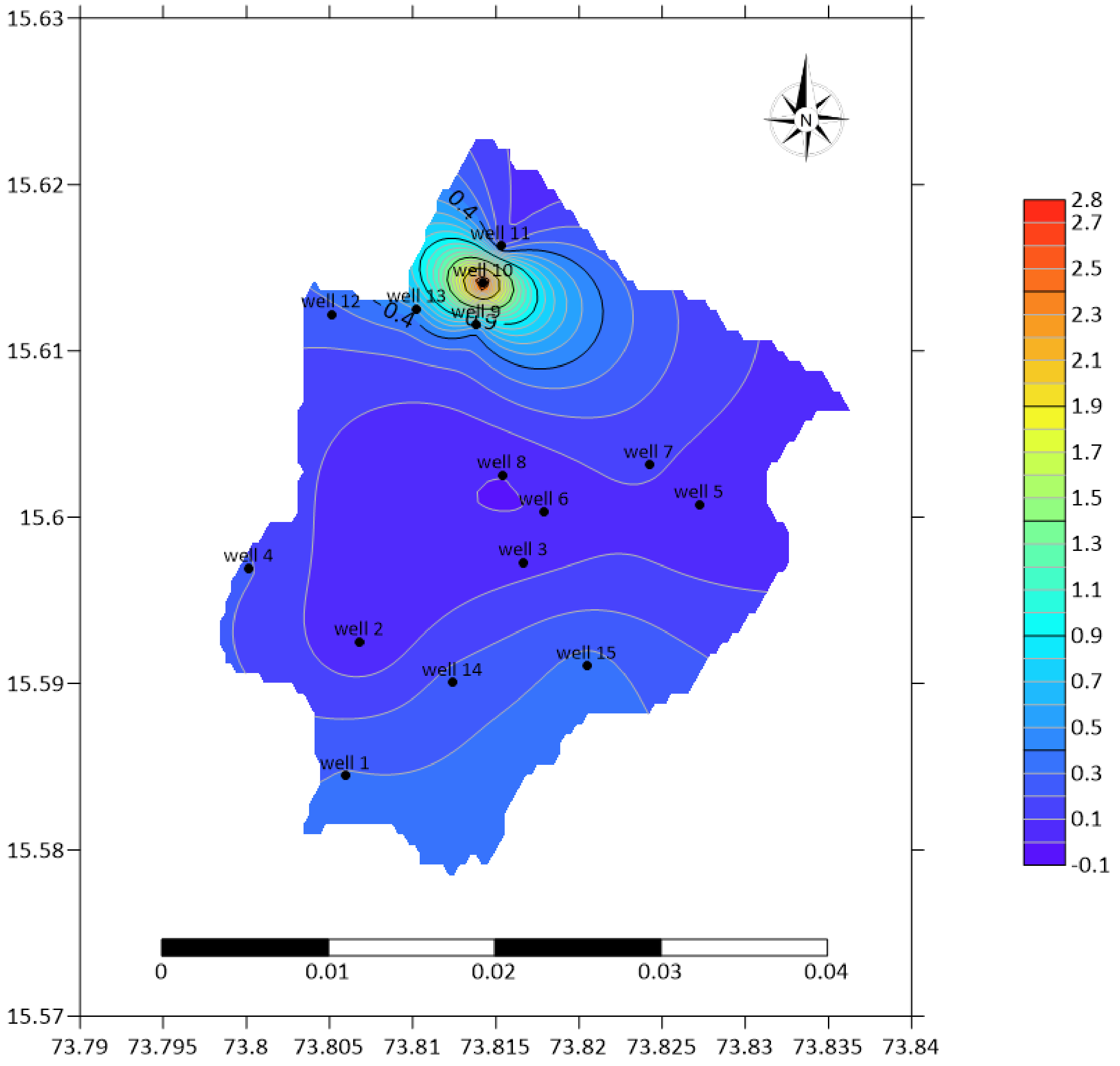

Figure 6.29: Contour Distribution of Metal Index Values

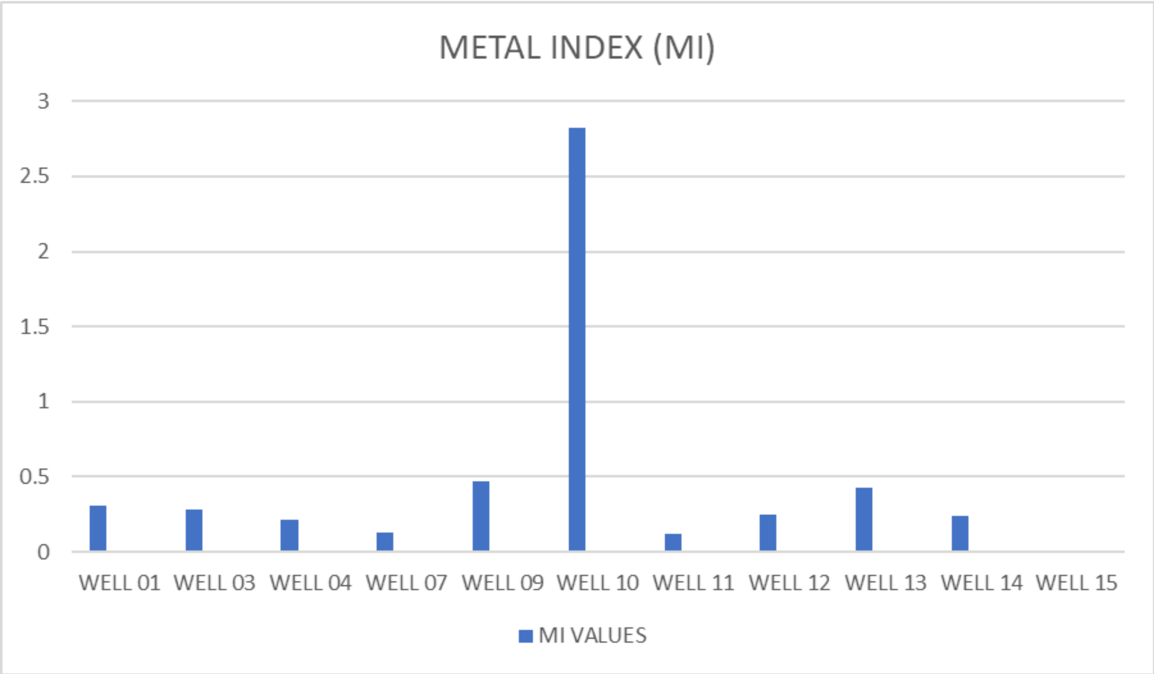

Figure 6.30: Graph depicting variation in the Metal Index Values

Inference:

The Well 10 was found to be heavily contaminated by Manganese concentration as per the MI. The reason behind the heavy contamination can be the infiltration of sewage during the rainy season into the groundwater. In addition, there was an abandoned toilet in the vicinity of 10m.

6.3 WATER QUALITY INDEX (WQI)

Table 6.19: Water Quality Index

WELL ID	WQI	STATUS
WELL 01	85.51	VERY POOR
WELL 02	48.43	GOOD
WELL 03	74.08	POOR
WELL 04	141.27	UNFIT
WELL 05	75.84	POOR
WELL 06	76.28	VERY POOR
WELL 07	37.37	GOOD
WELL 08	92.47	VERY POOR
WELL 09	105.10	UNFIT
WELL 10	128.86	UNFIT
WELL 11	79.14	VERY POOR
WELL 12	89.69	VERY POOR
WELL 13	66.27	POOR
WELL 14	101.50	UNFIT
WELL 15	109.20	UNFIT

Observations:

The WQI was calculated using 8 parameters we studied during the study such as pH, EC, TDS, Total Hardness, Calcium, Magnesium, Sodium, and Potassium concentration. In the table, the wells with their respective calculated WQI are given along with their corresponding status of the water quality.

As per the calculated value of WQI, it was found that only two were considered good for human consumption i.e. Well 02 and Well 07. Whereas, the remaining wells were either poor, very poor, or unfit for consumption quality based on the 8 parameters that we had studied.

The Well 03, Well 05, and Well 13 water samples are of poor quality. The Well 01, Well 06, Well 08, Well 11, and Well 12 water samples are considered very poor for drinking purposes. Furthermore, Well 04, Well 9, Well 10, Well 14, and Well 15 water samples are designated as unfit for human consumption based on the WQI. The pie chart illustrates the overall water quality based on 8 parameters as mentioned above, wherein no. of wells found good, poor, very poor, and unfit data is given.

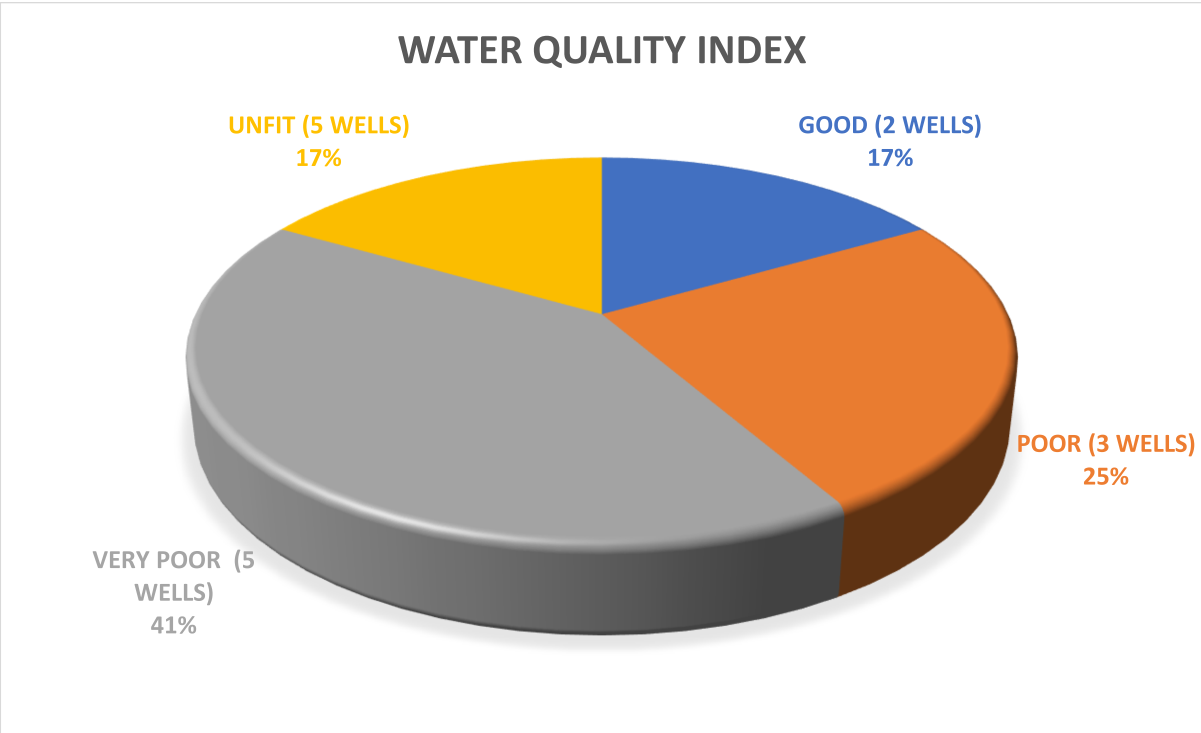

Figure 6.31: Pie Chart depicting the no. of wells of each category as per WQI

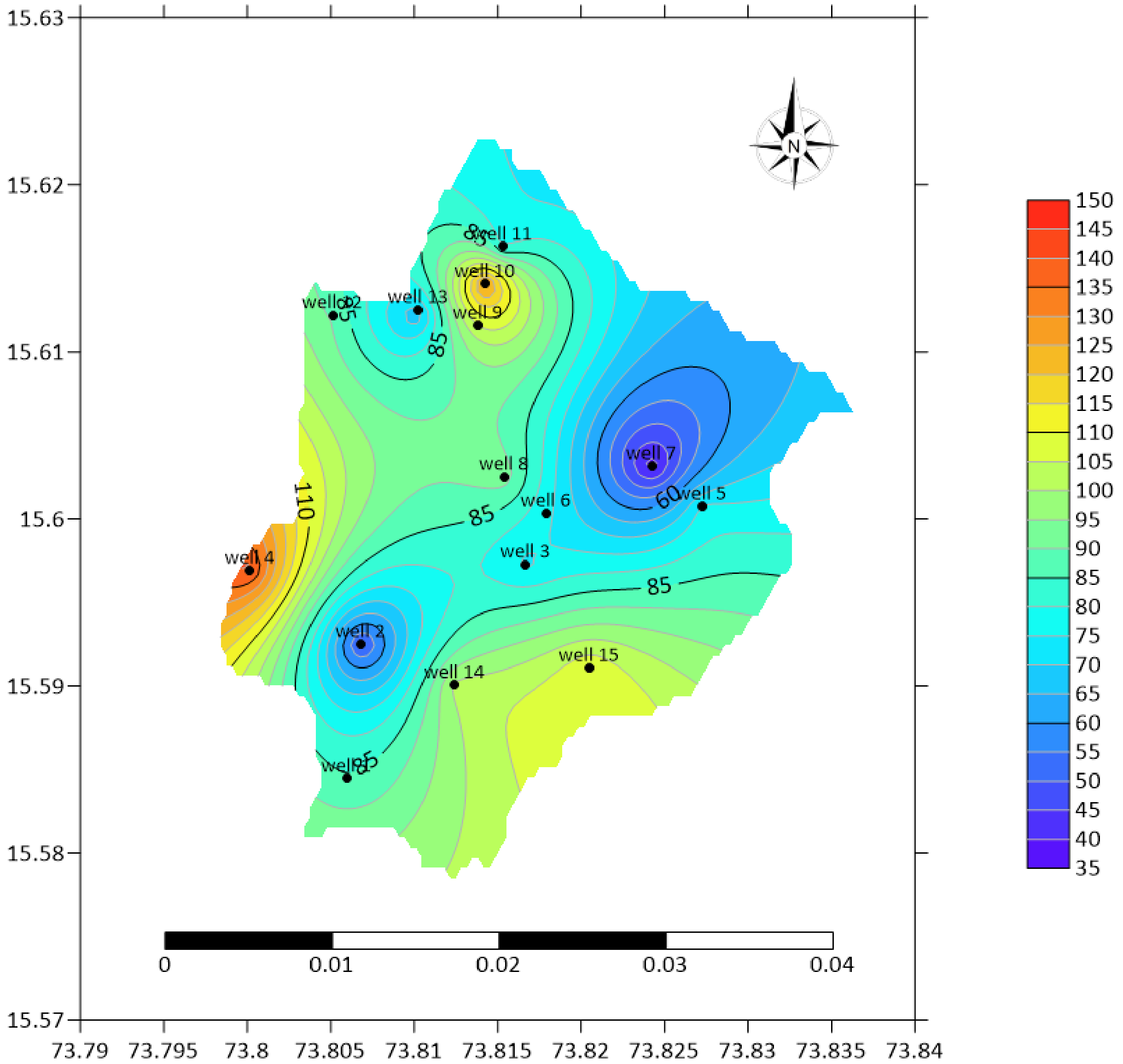

Figure 6.32: Contour Distribution of Water Quality Index Values

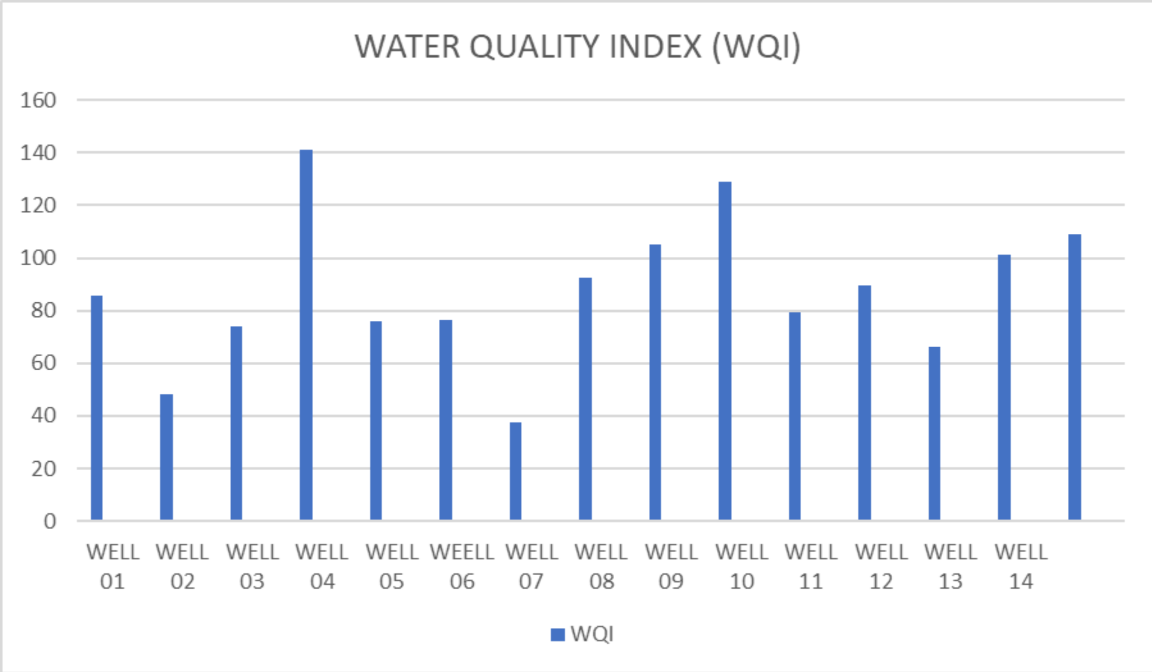

Figure 6.33: Graph depicting variation in the Water Quality Index Values

Table 6.19 gives the values of the WQI of each well, Figure 6.31 depicts the no. of wells of each category as per WQI. Further, Figure 6.32 and Figure 6.33 demonstrate the variation in the WQI values.

Inference:

The well water samples are considered as poor or very poor quality water because of various reasons such as acidic pH, high Electrical Conductivity, and high Total Dissolved Solids. However, the Total Hardness, Calcium, Magnesium, Sodium, and Potassium concentrations were within the permissible limits as per guidelines laid by the World Health Organisation (WHO) and Bureau of Indian Standards (BIS).

The well water sample was considered unfit for mankind's consumption when the pH was acidic or basic, Electrical Conductivity and Total Dissolved Solids became too high due to various reasons which might include domestic waste and groundwater interaction, run-off of fertilizers and pesticides from agricultural land, and decomposition of plant and microbes. In addition, the weathering of soil and rocks might have resulted in the overall unfit quality of the groundwater.

6.4 IRON CONCENTRATION

Iron contamination in groundwater is a common issue in many parts of the world. Iron is one of the most abundant elements in the Earth's crust which naturally occurs in the soil, water, and rocks. When the iron from the soils gets dissolved in groundwater due to being in continuous contact with the groundwater it leads to groundwater contamination. Sources through which iron gets leached out into the groundwater are the weathering of iron-bearing rocks and sediments, corrosion of iron pipes and wall casings, industrial and agricultural activities, and natural oxidation of iron-rich minerals. Ferrous Iron and ferric iron are the two forms of iron that can be found in water among which Ferrous Iron is commonly found in groundwater. While Iron is essential for human health, excessive consumption can lead to Gastrointestinal issues, nausea and vomiting, diarrhea, and stomach pain. The Bureau of Indian Standards (BIS) (2012) has established a maximum allowable limit of 0.3 mg/L (PPM) for Iron (Fe) in drinking water. Table 6.20 illustrates the exact amount of Iron found in each well water sample, as per the ICAR Report. Figure 6.34 and Figure 6.35 demonstrates the variation in Fe concentration in the groundwater.

Table 6.20: Fe Concentration in the wells

WELL ID	LATITUDE (DECIMAL)	LONGITUDE (DECIMAL)	Fe (PPM)
1	15.5844540	73.8059550	0.3057
3	15.5972810	73.8166730	0.2701
4	15.5969050	73.8001690	0.2076
7	15.6031700	73.8242330	0.1247
9	15.6115820	73.8138350	0.4617
10	15.6140660	73.8142520	0.1481
11	15.6163030	73.8153120	0.1163
12	15.6118000	73.8051200	0.2430
13	15.6122000	73.8102300	0.4265
14	15.5900570	73.8124250	0.2332
15	15.5910833	73.8205000	0.3301

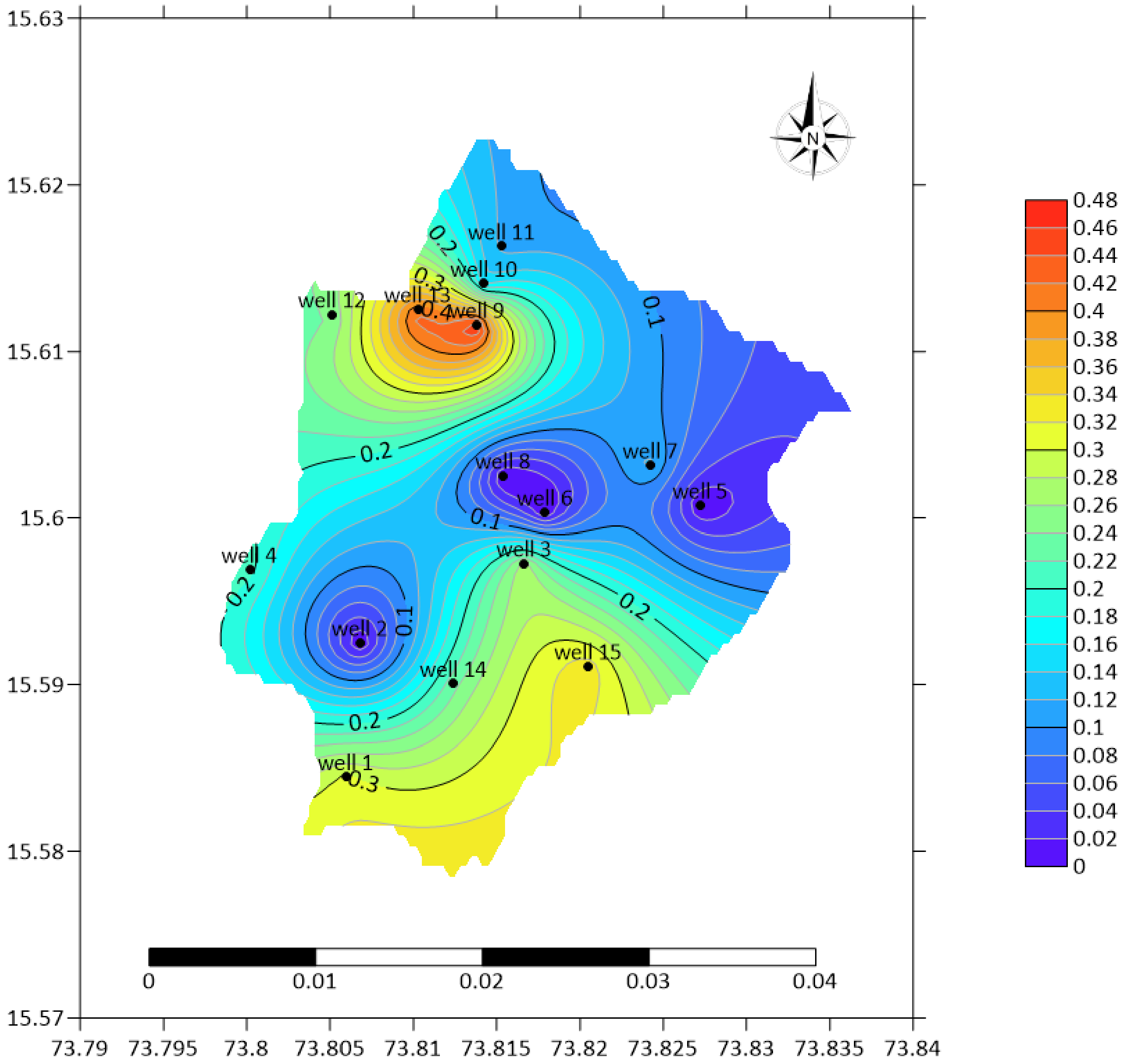

Figure 6.34: Contour Distribution of Fe Concentration

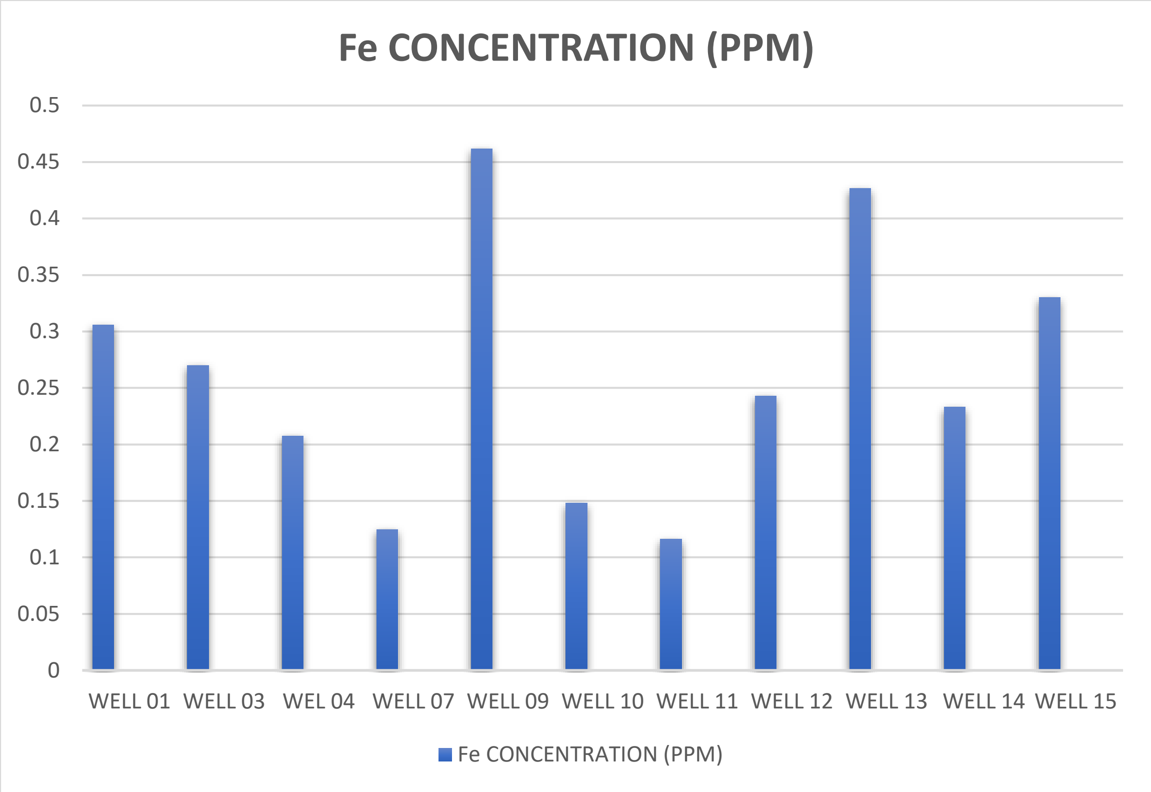

Figure 6.35: Graph depicting the variation in the Fe Concentration

Observation:

According to the ICAR Report, Well 01, Well 09, Well 13, and Well 15 had Fe concentrations higher than the BIS permissible limits i.e. 0.3 mg/L. The Well 03, Well 04, Well 07, Well 10, Well 11, Well 12, and Well 14 had Fe concentrations within the permissible limits laid down by BIS (2012). The average range of Fe concentration in the 11 well water samples was 0.1163 mg/L to 0.4617 mg/L. The highest Fe concentration was found in Well 09, followed by Well 13 which were 0.4617 mg/L and 0.4265 mg/L respectively.

Inference:

The higher concentration of Fe in some well water samples could be possibly due to a higher degree of weathering of Laterite.

6.5 ZINC CONCENTRATION

Zinc contamination in groundwater is a significant concern due to its potential health and environmental impacts. The Zinc concentration in the groundwater might increase due to weathering of Zinc-bearing rocks and minerals, industrial activities such as mining and smelting, agricultural runoff of fertilizers and pesticides, wastewater and sewage interaction with the aquifer, and corrosion of galvanized pipes and infrastructure. Higher concentrations of Zinc in groundwater can lead to various health complications due to long-term exposure such as Kidney failure, Anemia, and impaired immune function. Other health effects include Gastrointestinal issues, headaches, and dizziness. The BIS (Bureau of Indian Standards has established 5.0 mg/L (ppm) as the upper permissible limit for Zinc (Zn) in drinking water. Table 6.21 illustrates the exact amount of Zinc present in each well water. Figure 6.36 and Figure 6.37 demonstrate the variation of Zinc concentration in well water samples.

Observations:

All the 11 well water samples were within the permissible limit laid down by BIS (2012) i.e. 5 mg/ L. The Zinc concentration in the water samples had a range of 0.0911 mg/L to 0.1340 mg/L. The Zinc concentration was found slightly higher in Well 12 i.e. 0.1340 mg/L, followed by Well 04 i.e. 0.1124 mg/L.

Table 6.21: Zn Concentration in the wells

WELL ID	LATITUDE (DECIMAL)	LONGITUDE (DECIMAL)	Zn (PPM)
1	15.5844540	73.8059550	0.0955
3	15.5972810	73.8166730	0.1024
4	15.5969050	73.8001690	0.0891
7	15.6031700	73.8242330	0.1124
9	15.6115820	73.8138350	0.0911
10	15.6140660	73.8142520	0.0752
11	15.6163030	73.8153120	0.0889
12	15.6118000	73.8051200	0.1340
13	15.6122000	73.8102300	0.1069
14	15.5900570	73.8124250	0.0987
15	15.5910833	73.8205000	0.0920

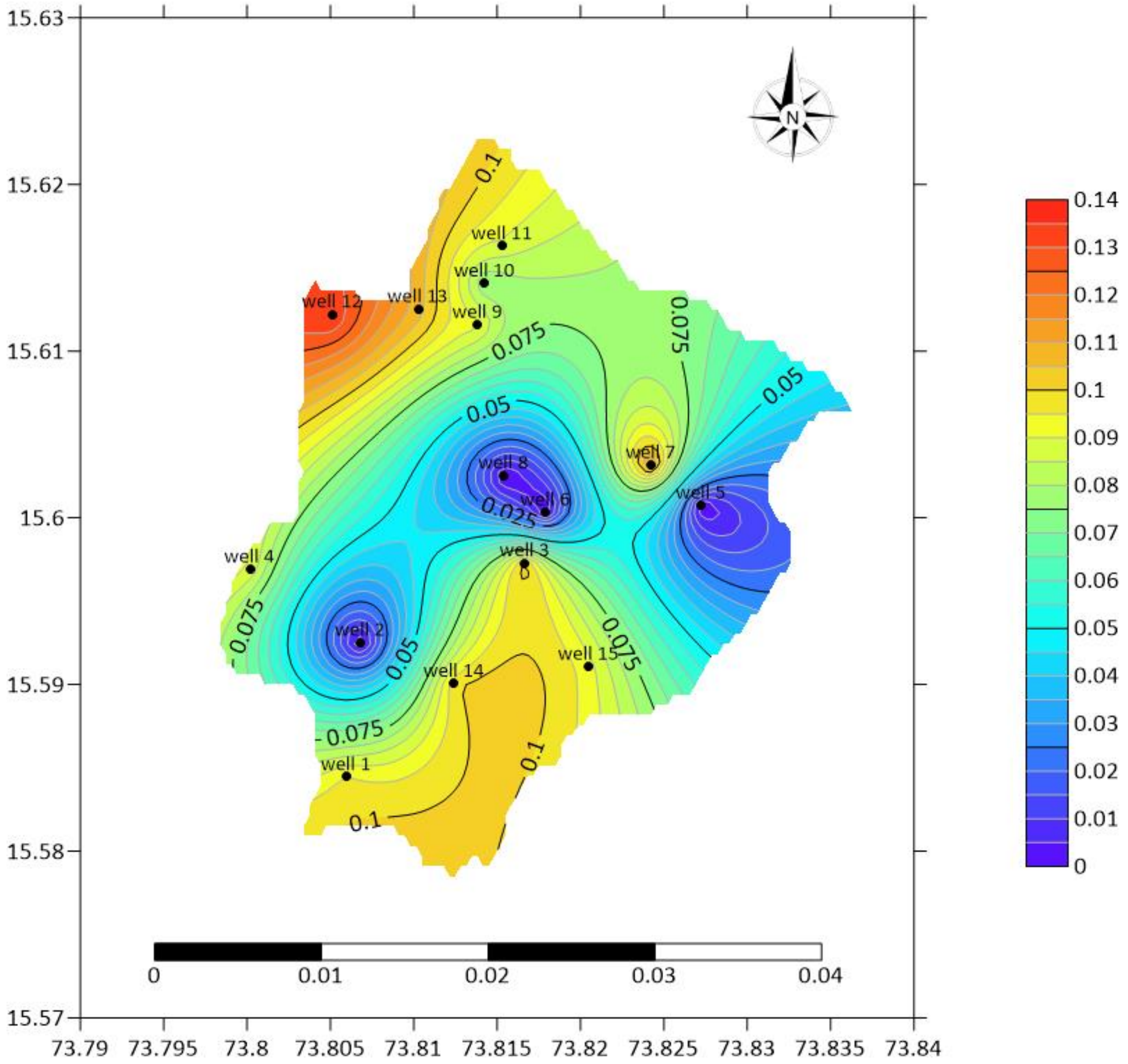

Figure 6.36: Contour Distribution of Zn Concentration

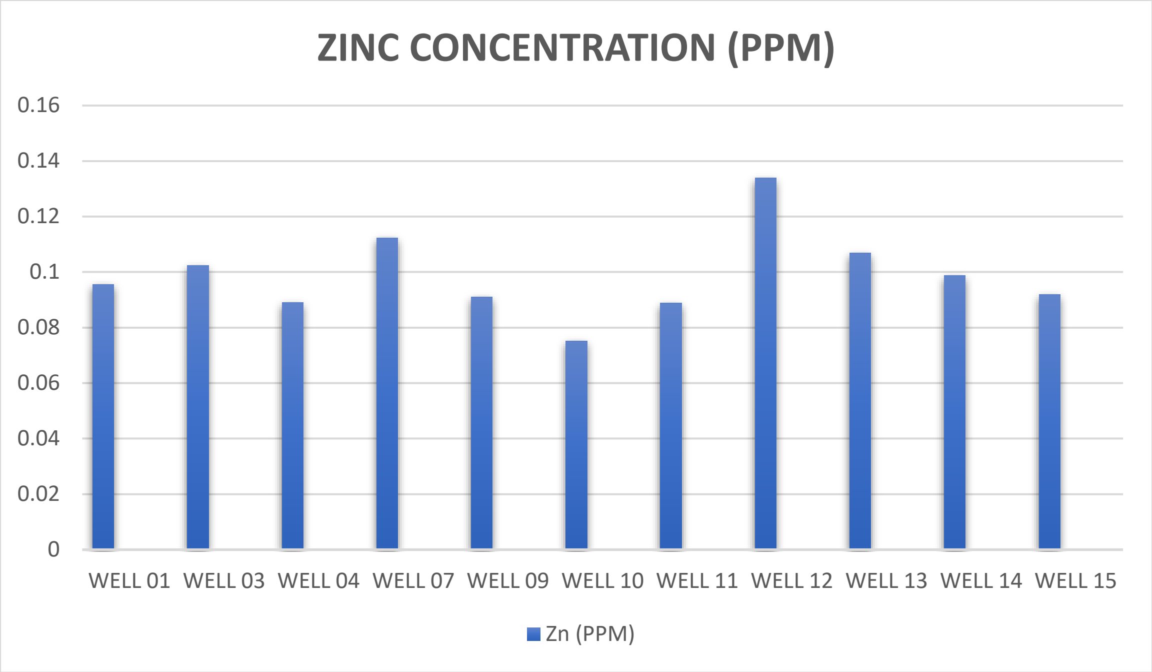

Figure 6.37: Graph Illustrating the variation in the Zn Concentration

Inference:

All the well water samples were within the permissible limits laid down by BIS (2012) i.e. 5 mg/L. However, some of the well water samples showed a little higher range than the rest water samples which could be possibly because of the interaction of groundwater with domestic waste, and agricultural inputs. Generally, the principal cause of Zinc contamination in groundwater is corrosion of galvanized metal i.e. pipes, wall casings, and steel.

6.6 MANGANESE CONCENTRATION

Manganese contamination in groundwater can occur from natural sources, such as weathering of manganese-bearing rocks and sediments such as mafic rocks containing Mg-rich minerals, or from human activities like mining and industrial discharges. Elevated manganese concentrations can cause serious health issues, including neurological problems, and aesthetic issues like coloring, black stains on plumbing fixtures, and metallic-tasting water. If you notice any above-mentioned water issues related to stain and taste. Testing for manganese is crucial, water treatment technologies like cation exchange, distillation, filtration, and reverse osmosis can remove manganese from drinking water. The maximum allowable level of Manganese (Mn) in drinking water has been set by the Bureau of Indian Standards (BIS) (2012) at 0.1 mg/L (ppm).

Observation

Manganese concentration was detectable in only one well out of 11 wells i.e. Well 10 which had a value of 0.7865 mg/L. However, the Manganese concentration was too high as compared to the permissible limit set by BIS (2012) i.e. 0.1 mg/L.

Inference:

A higher concentration of Mn in the groundwater sample of Well 10 could be due to the infiltration of sewage during the rainy season into the groundwater. In the rest of the wells, the Manganese concentration could not be detected due to being in very minute quantities which occasionally becomes challenging to find during analysis.

COPPER CONCENTRATION

Copper in groundwater can occur naturally or due to human activities. The natural sources through which Cu can seep into the groundwater regime include the weathering of Copper-bearing rock and minerals, sedimentary rocks, and soil deposits. The anthropogenic sources include industrial processes such as mining, smelting, and manufacturing, agricultural runoff of fertilizers and pesticides, corrosion of Copper pipes and fixtures, and waste disposal and landfill leachate. When the groundwater containing Copper in dosage is ingested, it can lead to health complications such as stomach problems, liver damage, and kidney damage. The permissible limit of Copper concentration in drinking water is set up as 2.0 mg/L by the Bureau of Indian Standards (BIS) (2012).

Inference:

The Copper concentration in all the 11 well water samples was not detectable.

CHAPTER 07: CONCLUSION

This study investigated the presence of trace elements such as Iron, Zinc, Copper, and Manganese. The study also analyzed physiochemical parameters such as pH, EC, TDS, and some major cations which include Calcium, Magnesium, Sodium, and Potassium.

1. As per the groundwater flow net, the groundwater was flowing towards the Moira River in the southern part of the map and to the Haran River in the northern portion of the map. The overall hydraulic conductivity was gentle and steady as depicted by evenly spaced equipotential lines

2. The average value pH of the water was found to be slightly acidic i.e. 5.86 which may be due to the recharge of groundwater by rainwater in post-monsoons. However, Well 04 was showing basic pH i.e. 9.9, which might be due to the long residence time and limited oxygen availability which in turn slows down the oxidation of minerals and reduces the formation of acidic compounds.

3. The average value of EC was 640 μS/cm in groundwater samples. In total 9 well samples were found to have EC higher than the permissible limits i.e. 400 mg/L which might be due to high levels of dissolved solids of salts and minerals.

4. The average value of TDS was 410 mg/L in groundwater samples. In total, 9 well samples had a TDS value higher than the permissible limits i.e. 500 mg/L. which might be due to agricultural activities and higher dissolved solids of salts and minerals.

5. The overall Total Hardness of groundwater was found to be soft water, however, in Well 10, the water was moderately hard.

6. The average value of Calcium concentration in groundwater is 9.92 mg/L. All the groundwater samples had Calcium concentrations within the permissible limit i.e. 75 mg/L.

7. The average value of Magnesium concentration is 38.6 mg/L. It was observed that 7 well samples had Magnesium concentration higher than the permissible limit i.e. 30 mg/L which might be due to weathering of Magnesium containing rock Laterite.

8. The average value of Sodium concentration is 14.21 mg/L. All the groundwater samples had Sodium concentrations within the permissible limit i.e. 200 mg/L.

9. The average value of Potassium concentration in groundwater is 10.41 mg/L. All the groundwater samples had Potassium concentrations within the permissible limit i.e. 55 mg/L.

10. With regards to the Heavy Metal Pollution Index (HPI), 5 well samples had low HPI value in the range (0-15), 5 wells had medium HPI value in the range (15-30), and 1 well had high HPI value in the range (>30). Wherein Well 10 had the highest HPI value i.e. 265.3, in this well Mn was the major contributor to heavy metal contamination. All the well water samples were found to be safe for drinking purposes, except for the Well 10 which was considered critical for drinking purposes which might be due to sewage interaction which was accelerated long residence time.

11. With regards to Metal Index (MI), 6 well samples came into the category of very pure, 4 well samples came into the category of pure, and 1 well sample came into the category of moderately affected by heavy metal contamination. The moderately affected well was Well 10, wherein, Mn was the major contributor to heavy metal contamination which might be due to the sewage interaction which accelerated with long residence time.

12. With regards to WQI, 2 well samples were considered good, 3 well samples had poor quality, 5 well samples had very poor quality, and 5 well samples were considered unfit for drinking purposes

13. The average value of Fe concentration in groundwater was 0.26 mg/L. The Fe concentration was found to be higher than the permissible limit i.e. 0.3 mg/L in 4 well samples. The highest concentration of Fe was found in Well 09 i.e. 0.4617 mg/L which might be due to weathering of Fe-rich Lateritic aquifer.

14. The average value of Zn concentration in groundwater was 0.10 mg/L. All 11 groundwater samples had low Zinc concentrations and were found to be within the permissible limit i.e. 5 mg/L.

15. The Manganese concentration was not detectable in 10 well samples. However, One well i.e. Well 10 had a Manganese concentration higher than the permissible limit i.e. 0.1 mg/L which might be due to interaction within the sewage.

16. In all the 11 groundwater samples, Copper was not detected since Cu concentration in groundwater was present in very minute quantities.

Finally, it could be concluded that most of the well water samples were safe for drinking purposes as far as tested heavy metals are concerned. Except for Well 10 which had a higher Heavy Metal Pollution Index (HPI) and Metal Index (MI).

With regards to WQI, when the physiochemical parameters and major cations were computed such as pH, EC, TDS, Total Hardness, Calcium, Magnesium, Sodium, or Potassium concentration, the result concluded that most of the wells were either poor, very poor, or unfit for drinking purposes, and only 2 well samples were considered to be of good quality. In addition, dumping of municipal waste along the roadside might have resulted in leaching through monsoons which in turn resulted in overall poor quality of water.

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